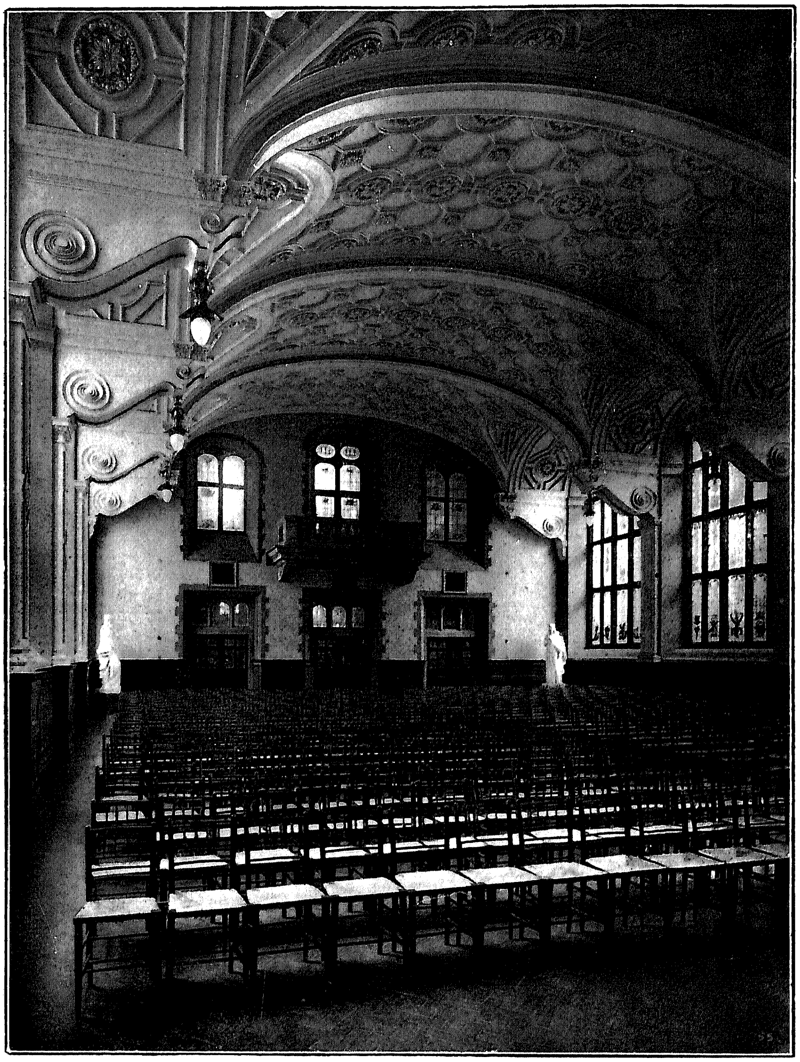
PLATE I.



Interior Lighting with Enclosed Arc Lamps in the Main Lecture and Examination Hall of the School of Technology, Manchester.

[*Frontispiece.*

ELECTRIC ARC LAMPS

THEIR PRINCIPLES, CONSTRUCTION AND WORKING

BY

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PROFUSELY ILLUSTRATED WITH OVER 160 *ILLUSTRATIONS*

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PREFACE

THE present volume is a study of arc lamps and their applications, and is intended to be useful to lighting engineers, students, and those engaged in the manufacture of the modern arc lamp or interested in its application for artificial lighting. The original work, written by Mr. J. Zeidler and published in Germany, has in the present English edition been greatly enlarged and brought up to date, additions having especially been made to the chapter on Flame Arc Lamps. Examples of manufacture chosen for description are of recent English, German, and American practice, so that the book will also be useful for reference to those to whom a complete survey of the subject is of value. For the sake of the student, an introductory chapter on The Electric Arc has been added, dealing with the main principles of its production and its properties.

In the chapter on Light Intensity and Illumination, some examples of exterior and interior lighting by arc lamps are discussed, and the method employed can be adopted to installations of similar or different character. The Standardization Rules of the American Institute of Electrical Engineers on Photometry and Lamps have been added as an Appendix.

I desire to express my obligations to my friend and former colleague, Mr. Ernest Classen, M.A., lecturer at the University of Upsala, for his valuable help in the preparation of the

English edition. Thanks are due to the various firms who have kindly supplied the blocks and information relating to their lamps; to Mr. W. Perren Maycock for description of the British Westinghouse flame arc lamp; and to friends, notably Mr. Arthur Bentley, for the reading of proofs.

J. L.

MANCHESTER,
December, 1907.

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ELECTRIC ARC LAMPS

CHAPTER I

THE ELECTRIC ARC

GENERAL REMARKS

The Open Arc.—Sir Humphrey Davy, in a lecture before the Royal Institution in 1801, speaks of a *spark* passing between two pieces of well-burned charcoal which was "of a vivid whiteness"; * however, it was not until 1808 that, with a battery of 2000 voltaic elements, he was enabled to bring "the electric flame" to general notice. With this large voltage and fairly large current he produced a continuous discharge through heated air nearly 3 inches in length and of a "vivid light."

If, with a sufficient voltage, a circuit carrying a large current be slowly broken, a great evolution of heat occurs with a consequent brilliant light, the colour of which depends to a certain extent upon the composition of the materials of the separated ends; the current maintaining the circuit by vaporizing the material and carrying it across the gap. With metals a P.D. of 10 volts or even less will be sufficient to maintain the discharge. When, as in Davy's experiment, carbon rods be chosen and connected to a direct current E.M.F. of at least 40 volts, on slowly separating their tips a brilliant white light results. It is this light which is produced in an ordinary arc lamp. In Davy's experiment the rods were

* *Journal of the Royal Institution*, 1802, vol. i. p. 166.

horizontal, and the discharge, influenced by an upward current of hot air together with its tendency to enlarge due to the expansion of the vapour, causes it to take the form of an *arch;* and in 1820, in describing the effect of a magnet on the discharge, he definitely named the electric flame—the *arc*. With the advent of vertical co-axial carbons, although the discharge is no longer arch-shaped, the name of arc still remains.

Owing to the intense heat, charcoal burns away very rapidly, and a considerable improvement was made in 1843 by the use of carbon from gas retorts, which lasts for a longer period, though it may be pointed out that charcoal gives a larger and more diffused flame. In 1877, Siemens Bros. introduced the "cored" carbon, in which the carbon is provided with a central core of carbon much softer than the rod. Modern arc lamp carbons (excepting so-called chemical or treated carbons) are generally made by mixing retort carbon with soot and coal-tar to form a thick paste, which is afterwards forced through dies under pressure, the resulting rods being baked to a high temperature. The softer carbons are rich in soot, whilst the harder ones contain more retort carbon. A needle, placed in the centre of the die, leaves a central space in the carbon rod for the core consisting of a mixture of carbon and sodium or potassium silicate which is squirted through; the cored carbon being afterwards heated to dry the mixture.

As the distance between the carbon tips in either the horizontal or vertical position is increased by actual burning away, or by hand manipulation, the resistance of the arc becomes greater, and with a given constant P.D. across the carbons the current falls until a point is reached when the arc will fail (unless the carbons are brought nearer to one another again). The arc is thus broken and the current can no longer pass through the carbon vapour that fills the space between the tips, until the carbons are *brought into contact once more and*

PLATE II.

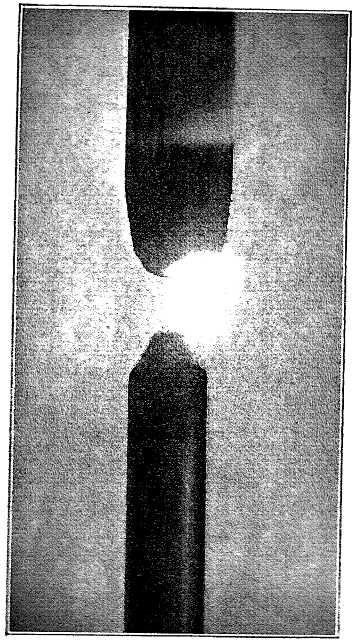


FIG. 1.—Direct Current Open Arc.

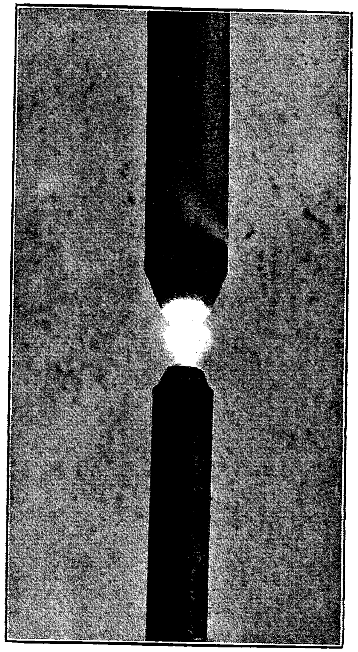


FIG. 2.—Direct Current Open Arc.

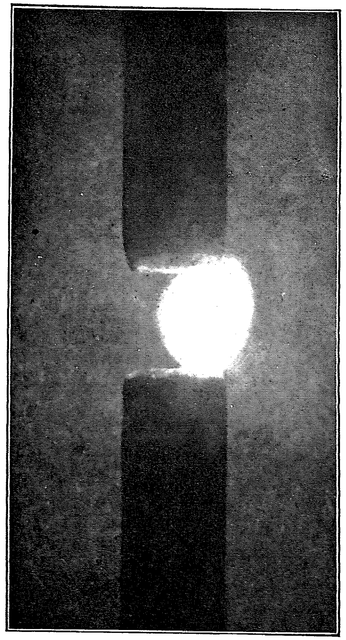


FIG. 3.—Enclosed Arc.

[To face page 2.

separated. Starting the arc in this manner is called "*striking the arc.*" The operation of diminishing the distance after the carbons are separated a certain amount due to consumption of the carbons is termed "*feeding.*" We shall see later that the arc lamp mechanisms are designed to perform the first operation automatically, and generally the second.

With direct current the carbon connected to the positive pole of the supply burns away more rapidly than the negative, since the major portion of the energy is being consumed at its tip, and it becomes more or less pointed, but having a depression at this tip called the *crater* (Fig. 1, Plate II.). The longer the arc the more shallow is the crater, the depression practically disappearing for arc lengths greater than the diameter of the positive carbon. The negative carbon has a white-hot spot on it (Fig. 2, Plate II.), and after burning some time a fringe of seething globules, consisting of tar and silicate, forms at the junction of the luminous and dark parts of the carbon.

The arc has a violet interior zone, bounded by a dark shadow and then by an exterior greenish-yellow zone.

The crater is the source of most of the light emitted in the usual direct current open arc (*i.e.* one burning in air). About 85 per cent. being due to the positive carbon, 10 per cent. to the negative, and about 5 per cent. to the arc itself.

Fig. 1 shows the normal shape attained by an open arc. The positive carbon surrounding the crater becomes blunt, whereas the negative carbon end becomes more pointed; the lengths of the tapering parts in both are increased by increasing the current and shortening the arc. With a very short arc and a large enough current, accretions build up a "mushroom" tip on the negative carbon and, with a longer arc, a rounded tip (Fig. 2). We have here, therefore, an indication whether the arc burns normally or not. This mushroom deposit, caused probably by carbon deposited from the crater, interferes with the formation of a proper arc, and also interferes seriously with the light of

the crater. It also gives rise to an unpleasant hissing noise. It may be pointed out that this hissing occurs not only with a very short arc, but also with any length of (open) arc, provided that the current is sufficiently increased. The hissing seems to be due to the crater extending and becoming too large to occupy the positive carbon tip. The extension is up its side and comes directly under the influence of draughts of air which, in producing products of combustion, *burn* the carbon more quickly than when the crater, occupying the extremity only and protected from the direct influence of air by the surrounding carbon vapour, *volatilizes* to pure carbon vapour.*

The large consumption of energy at the crater produces a high temperature there, which Sir William Abney in 1881 announced was that of the volatilization of carbon, and hence *constant.* M. Violle found this constant temperature to be about 3500° C., though Rossetti estimated it at 3900° C. The negative carbon tip has a lower temperature, probably 3000° C. The high temperature exists only at the extremities and between the carbon ends, since the temperature falls off very rapidly from the crater and the negative hot spot. For a particular quality of carbon the brightness or intrinsic brilliancy (*i.e.* amount of light per unit area) of the crater will therefore also be constant, irrespective of the currents used. A greater supply of energy does not raise the temperature, but simply increases the area or depth of the crater, and *vice versâ*. An increase in the pressure of the surrounding medium would, on the other hand, cause a rise in the temperature of vaporization, and would also result in increasing the minimum P.D.

* Mrs. Ayrton, "The Electric Arc," p. 308: "The sudden diminution of P.D. that accompanies the hissing of the open arc is due to the oxygen in the air getting directly at th· crater and combining with the carbon at its surface."

P. 301: "No sudden diminution in P.D. could be observed when the current through an *enclosed* arc is raised to higher values."

necessary to maintain an arc of given length. Softer carbons have a lower intrinsic brightness than graphitic ones.

Mrs. Ayrton suggests that the carbon vapour leaving the crater for a small distance is practically unaltered in temperature and invisible, but beyond this distance, owing to cooling of the surrounding air, it condenses into a mist of finely divided particles of carbon. This mist is the portion of the arc which is violet. The surrounding air not only cools this vapour, but unites with a certain thickness of it, forming an envelope of burning gases around the invisible carbon vapour and the mist, as well as part of the carbons themselves. It is the latter portion of the arc which burns with a greenish flame.

The current passes mainly through the carbon vapour and the finely divided carbon mist, since the specific resistance of the gaseous envelope is very high. The specific resistance of the vapour is higher than that of the mist, and owing to the thin layer a large part of the energy, *i.e.* of the P.D., is absorbed in it, and this probably maintains the volatilization of the crater.

The arc when burning between pure solid carbons, with direct current, acts as if a counter E.M.F. of 39 volts were set up, and is unsteady with a less P.D. than 40 volts. It is almost agreed that this fall of P.D. is due to the resistance of the above-mentioned thin layer. The arc voltage e comprises—

(1) A P.D. to overcome the fall from the positive carbon to the arc;

(2) A P.D. for the arc proper; and

(3) A P.D. to overcome the fall of P.D. (probably a true back E.M.F.) from the arc to the negative carbon. The approximate formula for e is—

$$e = a' + \frac{bl}{\mathrm{I}} + c'$$

where a' = P.D. at the positive carbon,

c' = true back E.M.F. at the negative carbon,

l = length of arc, I = current in amps., b = a constant.

The so-called back E.M.F. of the arc is $a' + c' = a =$ a constant. Thus—

$$e = a + \frac{bl}{I}$$

A more general formula given by Mrs. Ayrton, including the influence of the current on the sum $a' + c'$ and the influence of the length of arc on a', is—

$$e = (a + \frac{\text{constant}}{I} + \text{constant} \,.\, l) + \frac{bl}{I}$$
$$= a + cl + \frac{d + bl}{I}$$

where a, b, c, and d are constants depending on the carbons used.

Coring the carbons reduces the total P.D., which reduction is due, no doubt, to the presence of the more conducting vapour.

Carbons treated with chemicals will have a lower value for a owing to this increased conductivity of the arc, the salts being easily led into the arc. Moreover, the other constants will also be altered—and, in general, will depend on the particular chemical flame arc employed.

For a constant arc length l—

$$e = a + cl + \frac{d + bl}{I}$$
$$e = \text{constant} + \frac{\text{constant}}{I}$$
$$e = A + \frac{B}{I} \text{ or } (e - A)I = B = \text{constant}$$

Showing that as I increases, e falls, following a hyperbolic law.

Again, if I = constant—

$$\begin{aligned} e &= a + \frac{d}{\mathrm{I}} + cl + \frac{b}{\mathrm{I}}.l \\ &= \text{constant} + cl + \text{constant}.l \\ &= \mathrm{A}' + \mathrm{B}'.l \end{aligned}$$

which gives a linear law for the total P.D. e in terms of l.

The positive carbon is consumed about twice as fast as the negative, and the consumption amounts to 1 to 2 inches per hour, according to the diameter and hardness of the carbons. In the arc lamp the positive is usually cored with a softer carbon, and this has the effect of steadying the arc, which otherwise tends to wander and gives an undesirable fluctuating lighting effect. The negative is, as a rule, solid and made of a smaller diameter in order to obstruct as little of the light as possible and to equalize the rate of consumption with the positive carbon.

The Enclosed Arc.—In 1846 Staite discovered that the carbons enclosed in a glass vessel to which the access of fresh air is checked burned away at a less rate than in open air. It was not until 1880 that various constructions of enclosed arc lamps were attempted, but with poor results, as the attempts were made with 40 volts P.D., which required such a small distance between the carbon tips that very little light was given out. In fact, it has been found that the negative carbon builds up a mushroom tip for voltages below 65. But 1893 was the year of a marked improvement, when Jandus burned his enclosed arc with nearly 80 volts. The longer arc necessitating this high voltage causes a distinct difference in the light distribution, the light being freely radiated without being intercepted much by the negative carbon. Though its distribution is better than that of the open arc it requires more energy for the same amount of light given out. The principle of the enclosed arc is simple. Being enclosed in a vessel with a closely fitting cap through which the upper carbon enters, the fit being as

close as proper feeding permits, the oxygen is rapidly burned up and the resulting heated gases check a further supply of fresh air. The carbon wastes away at the rate of $\frac{1}{8}$ of an inch per hour, hence the lamp requires less attention. There is no definite crater formed as in the open arc, the tips of both carbons become flat. Since the section of the arc does not cover the area of the carbon tips and the arc seeks the shortest distance between, a constant wandering of the arc results,* which, altering the distribution of the light, may vary it by 30 per cent.

Fig. 3 (Plate II.) represents an enclosed arc with solid carbons. The positive carbon tip is very slightly concave, whilst the negative carbon tip is somewhat convex. The arc has the same pear-shaped form as the interior violet zone of the open arc, but still it does not produce a crater. There is merely the slight concavity, which would have been a definite depression were it not for the constant movement of the arc, hence this is termed the "crater." A cored positive does not prevent the arc from wandering. Only by the use of thin carbons, so that the whole section of the arc covers the tip, can the movement of the arc be prevented; but the advantage of increased time of burning is then lost.

The dark band and the greenish sheath are missing in the enclosed arc, as would be expected. The greenish sheath consists of a combination of carbon vapour and oxygen, which latter is wanting in the air-tight enclosure. The flat formation of the tips is therefore accounted for by the absence of the greenish flame, which in the open arc burns the sides of the carbons and gives them their pointed shape, the hot carbon vapour at the same time shaping the crater. Of the 80 volts across the arc, about 39 volts are needed, as in the case of the open arc, for the drop in P.D. from the positive carbon to the

* If the tips of enclosed arc carbons be examined closely, they will be found to be pitted with numerous small craters.

PLATE III.

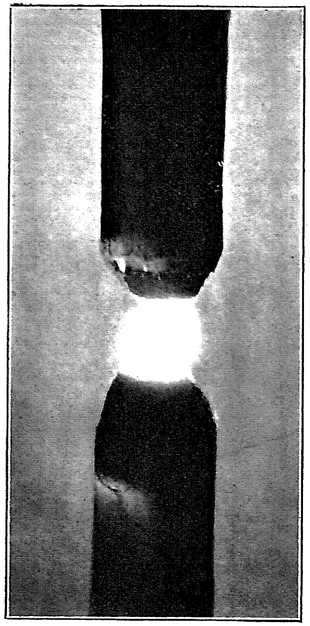


FIG. 4.—Alternating Arc.

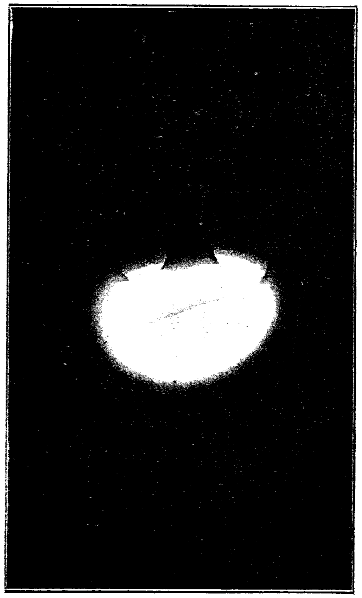


FIG. 5.—Direct Current Flame Arc burning normally.

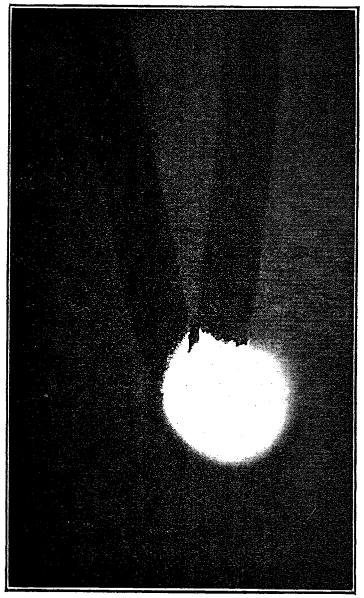


FIG. 6.—Direct Current Flame Arc of short length and in act of feeding.

[To face page 8.

arc. About 4 volts for the P.D. from the arc to the negative carbon, and the remaining 37 volts for the arc proper.

Alternating Current Arc.—With alternating current there will evidently be no marked crater on either carbon, and the two will burn at about the same rate. Owing to the current changing sign, each carbon in turn will become the positive, thus the positive crater will change its position at every half period of the current. Consequently, the carbon tips will have the same shape (Fig. 4, Plate III.). And if we consider the *instantaneous* values of the distribution of P.D. in the arc they are similar to those of the direct current arc, namely, that the total P.D. consists of a drop at the surface of the + *crater* to arc, a drop in the arc proper, and a drop at the – *crater;* the P.D. drop at the + crater being always greater than at the – crater. Since this total P.D. is pulsating in value, there is obviously an intermittent supply of energy to the arc, and hence the light must be of a pulsatory character, which is more pronounced at the lower frequencies. In fact, if the hand be moved rapidly to and fro in the light of the arc with low alternations, we shall see a number of images, one for each alternation. Thus the arc is extinguished once in each pulsation, and evidently the duration of extinction is increased with the lower frequency.

It has been found that the P.D. required to re-light the arc increases rapidly with the longer duration of extinction. A high E.M.F. impressed on the arc in series with a self-induction (choking coil) would therefore give stability to the arc, as it would ensure a high E.M.F. when the current vanishes.

The alternate arc causes a distortion of the wave form. The first person to note it was Joubert, in 1880, since which time many experimenters have investigated this reaction, and the reader is referred to "Experiments on Alternate Current Arcs by aid of Oscillographs," by Duddell and Marchant,* for a very

* *Journal Inst. E. E.*, Parts 138 and 139, vol. xxviii.

complete investigation of the effect of resistance, self-induction, frequency, and different makes of carbons, etc., on the arc. The results of their experiments show that with a high voltage and solid carbons and *small* self-induction in the circuit, the arc P.D. wave is flat-topped with a high front peak, the current remaining low for a considerable part of the period; the power factor is low and the arc is unstable. Increasing the self-induction makes the P.D. wave more rectangular, the current no longer remains small for any sensible period, the power factor improves, and the arc is more stable. This high front peak, especially prominent in long arcs, is due to the high resistance of the gaseous column after each extinction of the arc. With soft-cored carbon, the reaction is generally small, the power factor is nearly unity, and the arc is very stable. In practice, cored carbons are used in the alternating arc lamp; they unite with the above advantages over solid carbons a central position of the arc and a lower P.D. for the arc. Two solid carbons would require about 48 volts, whereas two cored carbons for the same current only need about 28 volts. One cored and the other solid would similarly require an intermediate P.D. of 35 volts.

An objection to the alternating current arc is the humming noise produced by it. This is partly due to the vibrations in the lamp mechanism and partly to the pulsations impressed on the air by the oscillatory action in the arc itself, which oscillation is due to the rapid expansion and contraction of the gases in the arc. The former vibrations are reduced by correct design and construction of the lamp, and the latter by using a soft grade of carbon whose vapour muffles the vibration. One or two volts with cored carbons make a large difference to the arc as to whether it is too long or too short. Whereas, with one solid and the other cored, the limits are widened nearly three times as much.

Enclosing the alternating arc produces a high peak on the

arc P.D. wave, and has only a small effect on the current wave; hence it would appear that enclosing the arc increases the resistance of the gaseous column. The change produced by enclosing the arc on the R.M.S. value of the total P.D. for the same length and current amounted to no less than 65 per cent. with Siemens' cored carbon used in Duddell and Marchants' experiments. Enclosing the arc reduces the power factor of the circuit, but the stability of the arc increases. Obviously the period of burning will be increased, but not as much as the direct current enclosed arc. The period of burning of the alternating current open arc is also less than that of the corresponding D.C. open arc, owing to the inrushes of oxygen (*i.e.* of air) to the arc caused by the rapid expansion and contraction of the gaseous column.

The pulsation in the light is somewhat reduced in the enclosed arc, and is almost inconspicuous when an opal outer globe is used (see p. 108).

Chemical or Flame Arc.—Bremer in 1898 discovered that by impregnating carbon pencils with a metallic salt like calcium or other rare metallic earth he was able to obtain a very luminous gas or flame as the arc. Whilst the chief source of light in the ordinary carbon arc is the positive crater (for direct current), in the chemical carbon arc it is not so. A 10-ampere chemical carbon arc was found to have a crater only about 65 per cent. of the area of 10-ampere ordinary carbon arc and with an intrinsic brightness less even than that of the soft core of a carbon crater.* Moreover, of the 2750 hemispherical candle-power † given out by this 10-ampere chemical carbon arc, less than 700 candle-power is emitted by the positive crater.

Fig. 5 (Plate III.) shows the more modern method of burning

* Leonard Andrews, "Long-flame Arc Lamps," *Journal Inst. E. E.*, vol. xxxvii. 1906. See also *E.T.Z.*, 1905, vol. xxvi., p. 67, article by Dr. Monasch.

† For definition, see p. 122.

the flame arc by inclined carbons. This gives a high light efficiency, as the crater and the negative carbon rays are not intercepted. The major portion of the light comes from the flame, and is doubtless due to the small particles being rendered highly incandescent. The intrinsic brightness of the flame is about one-third that of the positive crater (Fig. 6, Plate III.), but the area of the flame visible is many times greater than the area of the crater, which therefore accounts for the large amount of light given out by it. The amount of light given out is practically proportionate to the quantity of salt used. But with a very heavy "salting" a slag forms around the tip of the carbon, which is very objectionable. Hence, as a compromise, a carbon with a lower percentage of salt becomes necessary. The chemical carbons now made are composite. Blondel's carbons consist of an outer zone of carbon, to give mechanical strength, then a zone of carbon mixed with a metallic salt, such as calcium fluoride, then an inner softer core of the same mixture intended to hold the crater.

The essential point seems to be the use of fluorine compounds, and only the inner part (about one-third) is "mineralized." Some makers impregnate only their positive carbons. The colour of the arc depends on the base used—barium gives a white flame, strontium pink, and calcium a golden yellow. The calcium flame is the most efficient.

The salts are non-conductive, and make the carbon of much higher resistance; moreover, to get anything like a long-burning lamp, the carbon must be at least two feet long, and, with the employment of thin carbons, the question of their resistance is very important. Thin carbons are used in the inclined type, because the variation of the ohmic resistance of the flame when on the two outside edges as against the two inside edges of carbons of large diameter would not make it possible to burn the lamp with a fairly constant terminal pressure. This would cause a good deal of flickering; besides which, the wandering would cause a variation in the colour of

the light, depending on whether the arc was on the hard carbon shell—in which case it would be white—or whether it was on the impregnated zone. Metallic insertions are introduced into the carbon electrodes for arc lamps for the purpose of diminishing the resistance of the electrodes.

To increase the life of the electrodes, a departure has been made by using as a large constituent of the electrode a refractory conducting material (instead of carbon). This takes the form of a metallic oxide, and to it is added a fluoride or phosphate or a mixture of a fluoride and oxide of calcium or thorium or strontium, etc.* The "magnetite" lamp used in the States has copper for its lower positive electrode, and the upper negative consists of magnetic oxide of iron mixed with salts of chromium, titanium, etc. The arc produces a uniform white light of great brilliancy, and closely resembles that of a candle flame, having a bright and non-luminous zone. The bright zone is contiguous to the negative electrode which is made the upper electrode. A good air circulation is necessary in the lamp to remove the fumes, otherwise the latter deposit on the globe as a solid. It gives a maximum light intensity at 10° below the horizontal, and therefore favourable for street lighting. It is supposed to give a useful life of 150 to 200 hours' burning, and takes 4 amperes with an arc P.D. of 68 volts.

Further progress in flame lighting will probably lie in the judicious selection of materials as electrodes or as cores to carbons. It has been suggested that the "mineralization" should take the form of *base* like magnesia for the positive carbon, and for the negative carbon a metal forming an *acid*, like tungstic acid and chromium fluoride.

The total P.D. required for the carbon flame arc is about 45 volts (see p. 97), of which a P.D. of 17 volts is the drop from the positive carbon to the arc, and a P.D. of 18 volts in the flame arc.

* British Patent 6088, 1906, British Thomson-Houston Co.

CHAPTER II

THE ELECTRICAL PRINCIPLES OF ARC LAMPS

I. INTRODUCTION

THE utilization in practice of the light produced by an arc between two carbons requires a mechanism which strikes the arc, and automatically regulates the position of the carbons, feeding as they burn away during the continuance of the light, and maintaining a constant distance between the carbon ends. Broadly speaking, this mechanism, generally known as the arc lamp, consists of—

(*a*) An electrical portion which regulates the potential difference (P.D.) across the arc;

(*b*) A mechanical part to support the carbons and to regulate the feed; and

(*c*) The lamp case, which is provided with a glass globe in order to protect the regulating mechanism against dust and atmospheric influences and to shield the arc from draught, etc.

II. DIFFERENCES OF CONSTRUCTION

The differences in the construction of modern arc lamps may be grouped in three divisions—

A. Purely Electrical.—(*a*) According to the internal connections, into series, shunt and differential arc lamps.

(*b*) According to the kind of current, direct or alternating.

B. Electro-mechanical.—(*a*) According as to whether the electrical regulating mechanism is constructed with an electro-magnet or solenoid or an induction motor principle.

(*b*) Lamps with open or enclosed arc. In the former case sufficient air is admitted to the arc to maintain a pointed state of the carbons (Fig. 7). In the latter case the quantity of air admitted to the arc is limited, whereby a prolonged combustion with a given pair of carbons is possible. For this

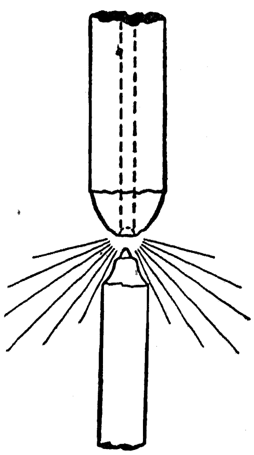


FIG. 7.

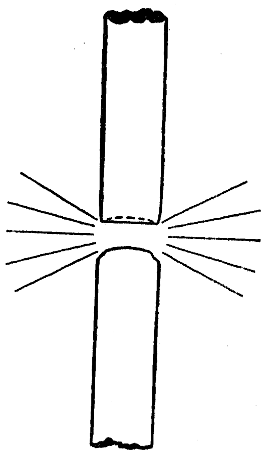


FIG. 8.

purpose the arc is surrounded as closely as possible by a small glass globe, and hence, owing to a smaller supply of oxygen, the carbon tips become flatter during combustion and the light less steady than in the case of the open arc (Fig. 8).

(*c*) Lamps for ordinary pure carbons and lamps for which the carbons are chemically treated (Flame arc lamps).

(*d*) Lamps for direct lighting in which the illumination is effected by the direct rays from the arc, and lamps for indirect or semi-indirect lighting in which the illumination is effected after single or multiple reflection of the rays (Fig. 9).

C. Purely Mechanical.—(*a*) Lamps in which the carbons

are situated either above one another (co-axial, Figs. 7 and 8), or inclined (collateral, Fig. 10).

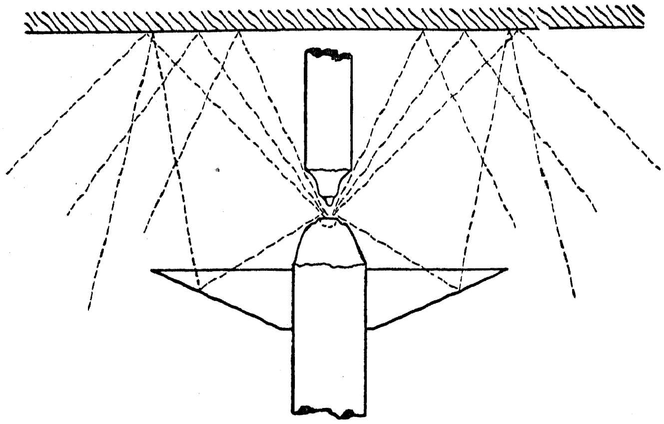


FIG. 9.

(b) Lamps with either a falling (non-focussing) or stationary (focussing) arc, according as the arc changes or maintains its relative position in the glass globe (Figs. 11 and 12).

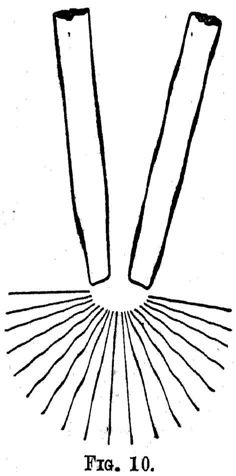


FIG. 10.

(c) Clutch feed lamps in which the clutch is attached directly to the carbon or carbon holder (Fig. 13); brake-wheel feed lamps (Fig. 14); and lamps in which a clockwork mechanism is affixed between the carbon holder or support and the arrest, in order to secure a more exact and frequent feed (Fig. 15). In all these cases the superincumbent weight of the upper carbon and upper carbon holder acts gravitationally as the motive power for the feed when the brake or arrest is released. In the latter case the clockwork frame

may be either fixed or pivoted—the latter is the more usual.

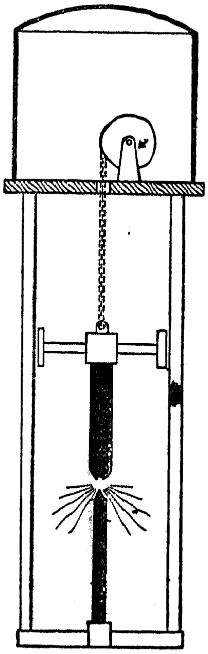


FIG. 11.

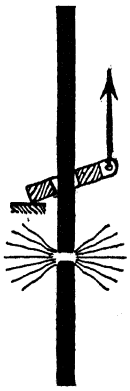


FIG. 13.

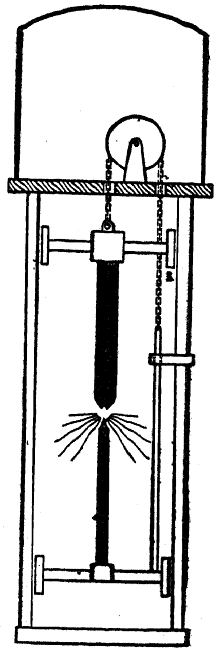


FIG. 12.

Finally, lamps with an induction motor principle (Fig. 16).

III. SERIES ARC LAMPS

INTERNAL CONNECTIONS

In series arc lamps the main current delivered to the arc serves to excite the electro-magnets (Fig. 17); effects, through the latter, the separation of the carbon ends, *i.e.* strikes the arc; and at the same time operates, irrespective of any particular distance between the carbons, the release of the mechanical portion and the feed of the carbons, as

soon as the current falls short of the normal proper to the design and regulation of the particular lamp. On the other hand, an arrest of the mechanical portion by means of the electro-magnets, with a consequent increase of the distance between the carbon points, takes place as soon as the current exceeds the normal amount.

Regulation.—Fig. 18 shows diagrammatically a series clutch

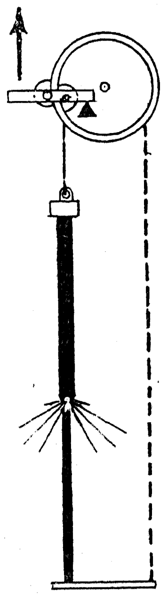


Fig. 14.

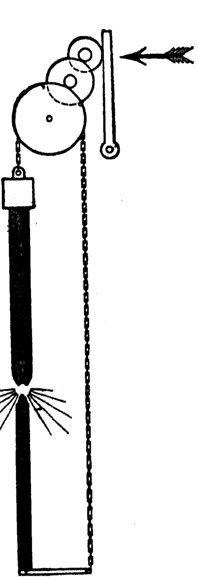


Fig. 15.

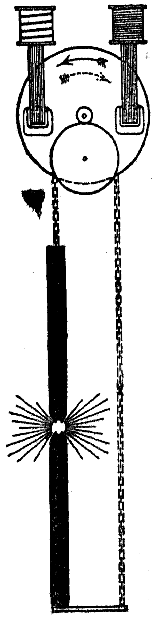


Fig. 16.

feed arc lamp, in which: S is a solenoid, wound with insulated copper wire, the diameter of which depends upon the current taken by the lamp; M is an iron core which is pulled into the solenoid when the current flows through the latter; F is a clutch fastened to M; A is a contact; C_1 and C_2 are the carbons, and R is a regulating resistance.

Since a complete circuit is only possible through the

carbons, the carbon tips in the series arc lamp must touch before switching in. After switching in, the current, taken from a supply of pressure E volts, passes through the solenoid S, the upper carbon C_1, the point of contact between C_1 and C_2, the lower carbon C_2 to a regulating arc lamp resistance R (usually

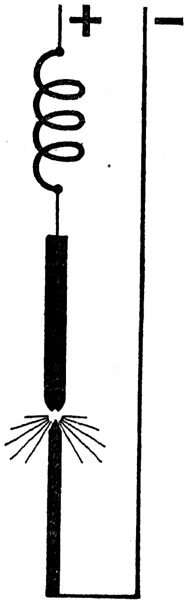


Fig. 17.

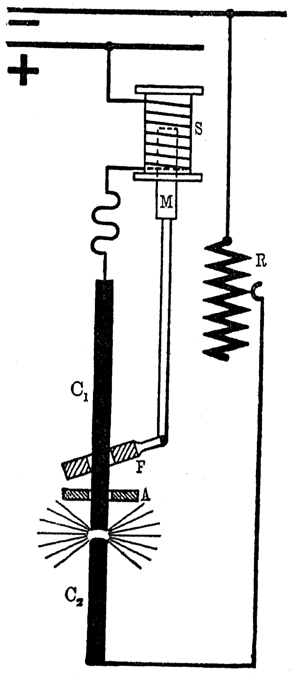


Fig. 18.

placed outside the lamp), the latter having a resistance equal to R ohms. The resulting current $I = \frac{E}{R}$ (assuming we are dealing with direct current and neglecting heat loss in the circuit as well as the usually small loss in the solenoid and the carbons) excites the solenoid so strongly that it pulls up the iron core M. At the same time the clutch F is pulled up on one side, grips the upper carbon, and raises it along with

M. The carbon points are hereby separated, an arc is struck and the circuit is maintained through the carbon vapour pro duced between the carbon points. The arc now introduces a additional resistance in the lamp circuit, in which that part (the main pressure necessary to maintain the arc is consume(Thus the arc causes a reduction of the current I wit increasing arc length and with corresponding increase of P.D. across the arc, until I $\left(= \frac{E - e}{R}\right)$ only excites the solenoid t such an extent that the attraction of the solenoid is in equil brium with the weight of the iron core and the upper carbo But the striking of the arc occasions a consumption of the ca bons and a correspondingly increased arc length, *i.e.* an increa in the P.D. across the arc. Hence the current I and tl attraction of the solenoid are still further diminished, so th the iron core and the upper carbon both fall. Hereby tl carbons are brought together, and I increases until equilibriu is again reached.

As soon as the burning away of the carbons has caus the iron core to fall so far that the clutch F touches t contact A, a further feed occurs through the release of tl arrest. When the iron core sinks still more, the clutch assum a horizontal position, so that the carbon slips freely through t hole in the clutch and the distance between the carbons diminished. In consequence, I becomes greater, the iron c(is pulled up and the upper carbon again arrested by the risi clutch. The current I reaches the normal and the feed arrest re-occurs according as the lamp current exceeds or fa short of the normal.

Constancy of Lamp Current.—Let IT equal the number ampere-turns of the solenoid where T = number of turns solenoid.

Then the attraction of solenoid = K × IT where is a co-efficient dependent upon the magnetic arran

ment of the solenoid and the position of the iron core within it.

If P represents the total weight of the portion moved by the solenoid, a balance is maintained when $P = K.IT$.

Since, however, under normal conditions, the position of the iron core relative to the solenoid remains, for practical purposes, unchanged, K remains constant for this normal position. Since the number of turns on the solenoid and the weight of the iron core and of the clutch are constant, and, moreover, since the consumption of the upper carbon only affects the weight very slightly (this, of course, must be so arranged in its design), within practical limits, the current $I = \frac{P}{KT} =$ constant.

Dependence of Arc P.D. upon Supply Pressure.—Since the resistance R and the current I are constant, it appears from the equation $I = \frac{E - e}{R}$, that the fall of pressure across the arc e can only remain constant if the supply pressure E is constant; otherwise e alters with a variable main pressure by exactly the same amount as E varies. Series lamps which burn with a short arc require, therefore, that the mains pressure should be as constant as possible.

EXTERNAL CONNECTIONS

Without special accessories, several series type lamps can only be installed in parallel, in which case a resistance R (Fig. 18) must be connected with every lamp. If two lamps were to be operated, in series with a correspondingly increased supply pressure, it appears from the equation $I = \frac{E - (e_1 + e_2)}{R}$, that if I, R, and even E remain constant, the individual P.Ds. e_1 and e_2 across the arcs of the two lamps may be different, if only their sum be constant. In both lamps there might be a simultaneous feed, although one lamp is already burning with too short and

the other with too long an arc. Only by means of auxiliary apparatus operated by the P.D. across the arc, which inserts a resistance in parallel with the solenoid, and thereby influences the ampere-turns of the latter, can the series type lamp be worked in series in practice. Moreover, with alternating current, series type lamps can be used in series by employing series transformers with a large no-load current, or by using choking coils with strongly saturated cores in parallel with the arcs.

IV. SHUNT ARC LAMPS

INTERNAL CONNECTIONS

In these lamps the winding of the control electro-magnet or solenoid (Fig. 19) is connected in parallel with the arc. The pressure at the ends of the coil is equal to the P.D. across the arc. Hence, in contrast to the series lamp, the coil must have a high resistance, and consequently consist of many turns of fine wire, so that in order to obtain the same number of ampere-turns as in the series lamp, only a small exciting current i is necessary, which, for 6- to 10-ampere lamps, amounts to 1 to 2 per cent. of the current I taken by the lamp. The value of the exciting current i (and the field strength of the solenoid accordingly) is, with direct current, dependent upon the resistance r of the coil of the solenoid, and upon the arc P.D. e,—$i = \frac{e}{r}$. Since r remains constant, when the maximum temperature of the lamp is reached,

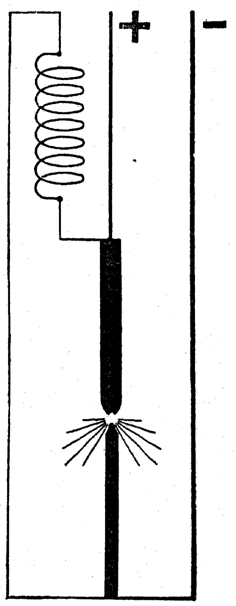


FIG. 19.

i alters in proportion to e. The release of the mechanical portion of the lamp for the purpose of feeding, etc., ensues as soon as the value of i (or e) exceeds or falls short of the normal determined by the construction of the lamp, whilst the lamp current I does not influence the regulation of the lamp. Hence the lamp is regulated by a constant arc P.D. In alternating current shunt lamps, i is dependent not only upon the arc P.D. and the ohmic resistance of the coil, but also upon the self-induction of the latter. Since the self-induction operates as an additional resistance to the magnet coil and increases or decreases with i,* then i no longer changes proportionately with e, but within narrower limits. Hence the regulation of shunt arc lamps with constant arc P.D. is, electrically, not so exact with alternating as with direct current.

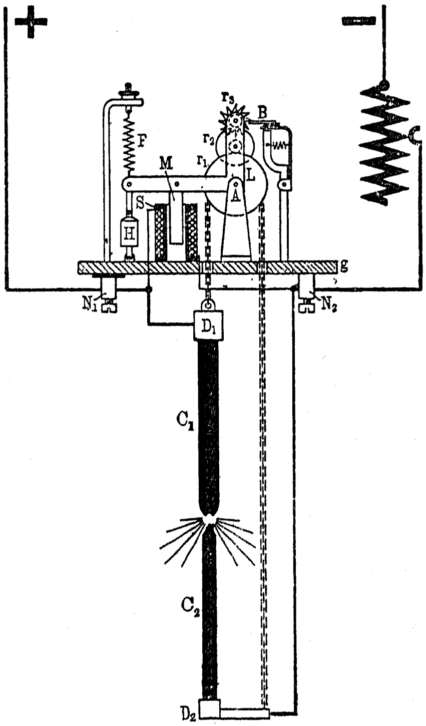


Fig. 20.

Regulation.—Fig. 20 shows diagrammatically a shunt arc lamp, in which, pivoted at A, is a frame, L, which carries a clock-work train fixed between the feed and the detent arrest. Suspended from the frame L is an iron armature, M, which is influenced by the solenoid S connected in parallel with the arc. F is a spring,

* Due to variation in permeability of the iron core.

attached to the opposite end of the frame (to balance the attraction of the solenoid upon the iron armature), which may be replaced by a weight. r_3 is an escapement wheel which, when the lamp is switched off, grips a detent or stop, B, attached to the base g. D is the holder for the upper carbon, the weight of which suffices, when the escapement is released, to set the wheel gear in motion and, by means of the mechanical connection (usually a chain), to pull up the lower carbon E and holder D_2. H is an air dashpot to weaken the momentary pull of the solenoid when carrying a large current, which usually happens when the arc is struck. N_1 and N_2 are terminals, C_1 and C_2 are the carbons.

As the operation of the solenoid only serves to bring the carbons together, the separation of the carbon points with a view to striking the arc must be effected by the spring F. Since the spring definitely comes into action when the lamp is switched off, and since the frame L is situated in its limiting position for a separation of the carbons, *the carbons must not touch when the lamp is cut out*, but must be separated by such a distance (8 to 10 mm.) as is suitable for the striking of the arc. R is a steadying resistance, connected in the lamp circuit, of such an ohmic value, R, that with the passage of the normal lamp current, there is a P.D. across it of about 30 per cent. of the arc P.D. Hence the mains pressure, E, must exceed the arc P.D. e by just that amount. If the lamp is connected to the mains, the circuit through the resistance R and shunt coil is first made. The resulting current is much less than the normal lamp current, and hence the fall in pressure across the damping resistance R is insignificant. The coil ends thus have across them a pressure which is very little less than the main pressure; i is therefore a maximum, and excites the solenoid so powerfully that the iron core M is drawn as far as possible into the solenoid. In this movement the lever pivoted at A participates, and brings the carbons

together. Before the iron core has reached the lowest point the escapement r_3 slips away from the detent B, and, if the separation of the carbons was previously so great that they do not touch by the swinging movement of L alone, a further feed of the carbons takes place by means of the weight of the upper carbon holder causing the train of wheels to revolve until the carbons touch. At this moment, since the resistance of the carbons is very small, the lamp is practically short-circuited through the steadying resistance, which will absorb practically the whole of the mains pressure. Hence the pressure on the lamp terminals and at the terminals of the solenoid is almost *nil*, and the solenoid S is practically without current. Consequently, under the influence of the spring F, the frame L separates the carbons, raises the upper carbon, and drops the lower one. The current I $\left(= \frac{E}{R}\right)$, produced at the moment the carbons come into contact, heats the carbons and forms the arc by which the circuit is maintained.

As in the series lamp, the pressure between the terminals of the lamp increases with the separation of the carbons, and provides the solenoid S with a correspondingly increasing current until a balance is reached between the attraction of the solenoid, S and that of the spring F. As the carbons burn away, a further separation of the carbons and an increase of the arc P.D., together with an increase of i, or attraction of the solenoid, take place. The iron core is drawn down whilst the lever gradually brings the carbons together, and strains the spring F until equilibrium is obtained. If, on account of the continuous burning away of the carbons and the gradually increasing P.D. across the arc, the solenoid has moved the iron core and the frame so far that the escapement r_3 comes quite clear of the detent B, then a further feed is supplied by the clockwork. The arc length is hereby diminished, the P.D. across the arc is reduced, the spring F outweighs the attraction

of the solenoid and arrests the wheel train by the stop B, until the regular play is resumed. The lamp has reached its normal P.D. across the arc e, and maintains it constant, independently of the lamp current.

Constancy of P.D. across the Arc.—Representing the attraction of the solenoid as in the series lamp, by $K . it$, in which t is the number of turns on the (shunt) solenoid of resistance r, and K a coefficient, which is constant for the normal position of the iron core; and representing the opposing force of the spring by P, which is also constant for this position, then the equation is—

$$P = K . it,$$

since, further, $i = \frac{e}{r}$, and r is likewise constant, therefore—

$$P = K . \frac{e}{r} . t$$

$$e = \frac{Pr}{Kt} = \text{constant}.$$

Dependence of P.D. across the arc, upon the regulating mechanism and increase in temperature of the winding of the solenoid.—In practice it is only possible to obtain an approximate constancy of e, since e must be somewhat greater for the release of the feed than for the arrest. The value of this difference $e_{\text{max.}} - e_{\text{min.}}$, which constitutes a measure of the regulation, depends upon the friction of the dashpot plunger and the tension of the spring F, which have to be overcome, and also, with direct current, upon the residual magnetism in the magnetic system. Apart from this, e is somewhat less when the lamp is cold (immediately after the striking of the arc) than when it is warm, because the resistance of the turns of the solenoid increases with a rising temperature. Hence the strength i of the feed current is, in the heated condition of the lamp, only reached with a correspondingly higher arc P.D. In lamps taking over 10 amps., this

disadvantageous heating may produce an increased P.D. amounting to 10 per cent. of the lamp pressure, if the winding of the solenoid be of copper wire. It is usual, therefore, to wind it partly with a resistance material which has a smaller temperature coefficient, whereby this increase in P.D. may be reduced to about 2 or 3 per cent. Similarly, the application of heat compensators, which diminish the tension of the spring F when the lamp becomes heated, or which alter the position of the detent B, serves to neutralize this defect due to heating.

Dependence of the Lamp Current upon the Supply Pressure.—From the description of the striking of the arc it is evident that a steadying resistance is absolutely essential to the shunt arc lamp. Were this not so, that is, were the supply pressure equal to the pressure at the lamp terminals, then, before the striking of the arc, no further increase of pressure at the terminals of the solenoid would be possible. The attraction of the solenoid would not suffice to free the escapement, since some friction must be overcome to set the clockwork in motion. But if the striking occurred by a slight increase of the main pressure, no steady arc could be obtained, because the lamp current itself, with absolutely constant P.D. across the arc, would vary between zero and an exceedingly high value according as the main pressure equalled or slightly exceeded the P.D. across the arc. The equation for the resulting current is here, as in series type lamps, $I = \frac{E - e}{R}$. But since e and R are constant, I varies with the difference $E - e$. If, for example, the normal pressure of the mains were made 1 volt higher than the P.D. across the arc, and if the variation of E only amounts to 1 volt, then the normal current would be $I = \frac{1}{R}$; with 1 volt increased pressure $I = \frac{2}{R}$; and with 1 volt decreased pressure $I = \frac{0}{R}$. That is to say, in the case of an

increased supply pressure of 1 volt, I would reach double the normal value, and in the case of 1 volt decrease, would be zero, *i.e.* the arc would be extinguished. Hence, in practice, about 25 per cent. of the supply pressure is dissipated in the steadying resistance and the remaining 75 per cent. in the lamp. If the mains pressure varies 2·5 per cent. above or below the normal, the current varies $\frac{2 \cdot 5}{25} \times 100 = 10$ per cent. above or below, which is permissible in practice.

In the equation $P = K.it$, and the resulting equation $e = \frac{Pr}{Kt}$, the lamp current I is not included, from which it follows that I has no influence upon the regulation; and from the equation $I = \frac{E - e}{R}$ we see that the strength of current with which shunt arc lamps ought to burn depends, with a given supply pressure and with a suitable pressure across the lamp terminals, *entirely upon the value of the steadying resistance.* This is the greatest advantage which these lamps possess, because by altering the external resistance, and without any change in the regulating mechanism, the strength of the current, and hence the intensity of the light, may be varied within such limits as may appear proper, and provided that carbons of suitable diameter are used. The value of the resistance (including the resistance of the leads in a single burning lamp) may be found from the equation $R = \frac{E - e}{I}$.

EXTERNAL CONNECTIONS OF SHUNT ARC LAMPS

From the equation $I = \frac{E - (e_1 + e_2)}{R}$, since e_1, e_2, and R are constant after adjustment, we see that two or more shunt lamps can be connected in series. Each of the lamps connected in series receives, however much the supply pressure may vary, an equal

amount of energy, because the P.Ds. e_1 and e_2, with a given design, depend only upon the tension or regulation of the spring F of each lamp, which may be made equal and remain constant. The lamps do not mutually influence one another in their electrical state of equilibrium. Consequently, for lamps connected in series in a circuit it suffices to have a common steadying resistance (including the resistance of the leads), which must absorb the difference between the sum of the lamp pressures and the supply pressure (Fig. 21). The latter difference must also amount to at least 25 per cent. of the supply pressure.

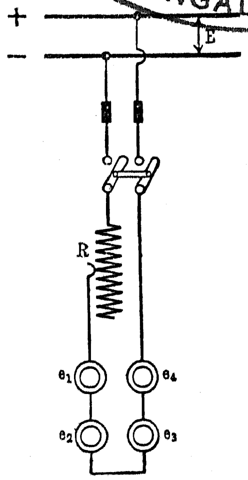


FIG. 21.

The equation, for the resistance, is then—

$$R = \frac{E - (e_1 + e_2 + e_3 + \dots e_n)}{I}$$

where $e_1, e_2, e_3, \dots e_n$, denote the pressures of the individual lamps connected in series.

V. DIFFERENTIAL ARC LAMPS

INTERNAL CONNECTIONS

The differential arc lamp unites in its electrical mechanism the current and pressure regulation of the arc. Its internal connections (Fig. 22) are a combination of the series and shunt arc lamps. The mechanical part is under the opposing influence of two electro-magnets, of which the series electro-magnet, connected in series with the arc, tends to form the arc, whilst the shunt electro-magnet, connected in parallel with the arc, tends to shorten the arc length. According

as the attraction of the series electro-magnet or that of the shunt electro-magnet predominates, an increase or decrease of the arc length occurs until the influence of the two magnets produces equilibrium. With increased length of arc the P.D. across the arc e increases, and with it, as in the shunt

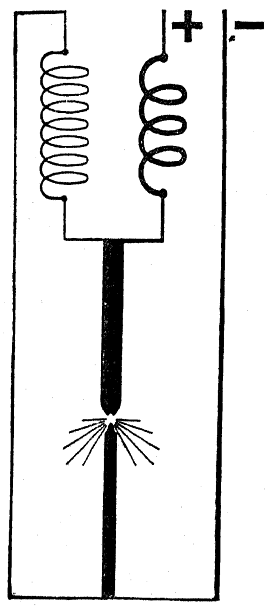


FIG. 22.

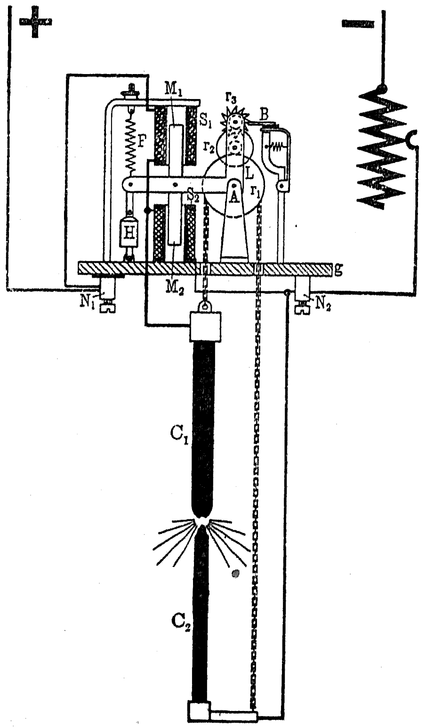


FIG. 23.

arc lamp, the pull of the shunt magnet increases. At the same time, presupposing a constant main pressure E, the strength of the series current $I = \frac{E - e}{R}$ is diminished, because the difference between the main pressure E and the P.D. across the arc

e must decrease, if the latter increases. With a reduced length of arc the contrary tendency sets in. Hence the regulation of the arc neutralizes the attraction of the magnets.

Regulation.—Fig. 23 shows diagrammatically a differential arc lamp with a level L, pivoted at A (as in the shunt arc lamp) and carrying the geared train of wheels r_1, r_2, and r_3 between the detent B and the feed mechanism. The remaining part of the mechanism is similar to that of the shunt arc lamp but for the addition of a series solenoid S, together with an iron core M, attached to the lever. When a current passes through the lamp, this solenoid S tends to pull up the iron core M. The force thus brought to bear on the pivoted lever L is exercised in a direction opposite to that which is exerted by the shunt solenoid S_2 on the core M_2, that is, on the lever L. The spring F may be either omitted or made considerably weaker than in the shunt arc lamp. If it is employed it only serves as a means of adjusting within narrow limits the strength of the current taken by the lamp, without altering the winding of the series coil. When the spring F is placed above the lever frame L as in the figure, it assists the attraction of the series solenoid. The state of equilibrium in the normal position in that case depends more upon the lamp terminal pressure than upon the lamp current. If the spring is placed beneath the lever it assists the attraction of the shunt solenoid, and the state of equilibrium then depends more upon the lamp current than upon the lamp terminal pressure. The former arrangement is to be preferred in so far as, in the case of several lamps in series, especially in the case of inexact adjustment for the required equal electrical conditions, the arc lengths show less variation—an advantage of particularly great value—if for any reason the lamps connected in series could not be adjusted together in the factory. The spring may, of course, be replaced by an adjustable weight. The moments which are exercised on either side of the pivot A by the weight of the mechanical

portion, *i.e.* the iron cores, holders, etc., are supposed to equilibrate.

For the striking of the arc it is immaterial, in the differential arc lamp, whether or not the carbons touch before the lamp is connected into circuit. If they do not touch, only the shunt solenoid S will first carry the small current i, so that the iron core M_2 is drawn downwards, and, as in the shunt arc lamp, will bring the carbons together, *i.e.* releases the arrest until the carbons touch. The moment they touch, the lamp is short-circuited and the shunt solenoid is consequently almost devoid of current, whilst the resulting series current $I = \frac{E}{R}$ (R = steadying resistance) is considerably greater than when the lamp burns normally. Hence the decreased attraction of shunt coil is opposed by the increased attraction of the series coil. Consequently, the iron core M_1 is raised by the coil S, and swings the lever so that the upper carbon holder is raised and the lower one dropped. Thereupon the carbons are separated and the arc is struck. With the striking of the arc, the P.D. e across the arc appears (owing to the resistance of the arc), so that now $I = \frac{E - e}{R}$. At the same time the shunt coil S_2 receives the current corresponding to the P.D. across the arc, so that through the striking of the arc, on the one hand, the current I, and hence the attraction of the series coil, is diminished, whilst, on the other hand, the attraction of the shunt coil is increased until, with a particular arc length, equilibrium between the two solenoids is established. The lever frame L in its final position is swung to the right, so that the detent B grips the escapement wheel r_3 firmly.

As the carbons burn away, the arc length and the P.D. across the arc increase, whilst the current I decreases. The attraction of the shunt solenoid is correspondingly increased and finally overcomes the attraction of the series coil, so that

wnward movement of the iron core and a motion er frame towards the left ensue. The carbons are ught together until, with a given value of e, equiligain reached. Finally, if the lever is turned so far scape wheel r_3 is quite free of the detent B, then, shunt arc lamp, a further feed is provided by the whilst e necessarily decreases and I increases. ing to the greater attraction of the series solenoid, frame is again turned towards the right and the n checked until the normal play is resumed. I and en reached the normal values determined by the n and regulation of the lamp and the supply

ncy of the Arc Resistance.—Representing IT and e, as the ampere-turns of the two solenoids, and K_1 coefficients respectively, which are constant for the sition (see p. 20). Then equilibrium is reached $K_1 = it \,.\, K_2$; assuming that the mechanical portion is o that, with the exception of the solenoids, there is e to influence it.

$= \frac{e}{r}$ (r = resistance of shunt winding), then we may for the above equation—

$$\mathrm{I}\,.\,\mathrm{T}\,.\,\mathrm{K}_1 = \frac{e}{r}\,.\,t\,.\,\mathrm{K}_2$$

$$\frac{\mathrm{T}\,.\,\mathrm{K}_1\,.\,r}{t\,.\,\mathrm{K}_2} = \frac{e}{\mathrm{I}}.$$

tio $\frac{e}{\mathrm{I}} = \frac{\text{P.D. across the arc}}{\text{lamp current}}$, which indicates the *resistance* of the arc, remains constant, because all on the left side of the above equation possess fixed lamp of given construction. *Hence the differential s regulated by a constant arc resistance.*

D

Dependence of the Lamp Current and the P.D. across the Arc upon the Pressure of the Mains.—As a result of the constancy of the *total* resistance (arc resistance + steadying and lead resistances), the lamp current must vary proportionately with the pressure of the mains (assuming direct current). Further, the value of $\frac{e}{I}$ remains constant only if e changes proportionately with I. *Hence it follows that the power* eI *expended in the production of the arc varies by twice as much per cent. as the variation per cent. of the pressure of the mains,* But since the intensity of the light is proportional to this energy for small variations of the normal current, it follows that in the differential arc lamp also, the supply pressure must not vary beyond certain limits if a steady light is to be obtained.

EXTERNAL CONNECTIONS OF THE DIFFERENTIAL ARC LAMP

From the above considerations of the regulation of the lamp with constant arc resistance, it follows that the external resistance of the circuit has theoretically no influence upon the variation of the intensity of light. It may therefore be omitted, *i.e.* the external resistance is only necessary to the striking of the arc as a starting resistance, in order that the current may not be too great at the moment of striking. In practice, however, with varying supply pressure, the light variations with a large external resistance are of less importance than with a small resistance, because however accurately the mechanism may be constructed, still some inertia and inexactness occur in the fitting of the regulating solenoids, due to residual magnetism and friction, and, in consequence, there may be some small variation in the ratio $\frac{e}{I}$. Also the adjustment described above requires some change in this

ratio during the intermittent feed. This change is, of course, so slight that the eye does not note the consequent light variation. Further, the regulation of the differential arc lamp with a constant arc resistance renders the possibility of working two or more lamps in series. Since e must vary proportionately with I, the various P.Ds. across the arcs must vary uniformly with a fluctuating supply pressure. Hence, with one adjustment, the light intensity remains the same in all the lamps.

CHAPTER III

CONSTRUCTION OF ELECTRIC ARC LAMPS

I. LAMPS WITH OPEN ARCS, AND CO-AXIAL VERTICAL CARBONS

A. DETAILS

IN these lamps, which are now always made with a fixed arc position, the following constructive details have to be considered.

1. *The Base Plate.*—On the upper surface of the base plate is erected the regulating mechanism, and on the under surface are attached the hollow frame tubes, on which or through which slide the rods carrying the carbon holders. The diameter of the plate for lamps of medium current strength (6 to 12 amps.) is about 6 ins.; the material is generally cast iron.

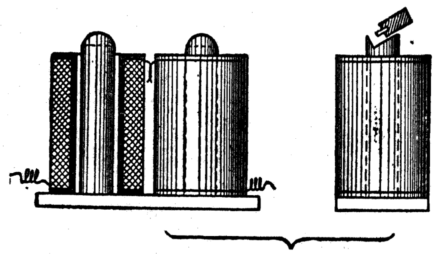


FIG. 24.

2. *The Electro-Magnets.*—In direct-current lamps these are frequently made in the form of a horseshoe, with fixed massive iron cores, and a movable armature, which faces the poles (Fig. 24). They are also constructed in solenoid form with

a movable iron core or plunger. The material for the core and armature must be well-annealed soft iron retaining very little residual magnetism, since the latter has an injurious effect upon the regulation of the lamp. The pivot upon which the armature (Fig. 24) works is placed as near as possible to the base plate, and in such a manner that an imaginary plane drawn through this pivot and the centre of the armature makes an angle of 30° to 45° with the plane which passes through the axes of the magnet cores. The solenoid form is usually employed with alternating current, in which case the cores are composed of iron tubes slotted lengthwise (Fig. 25),

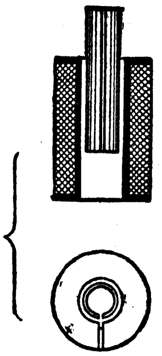


Fig. 25.

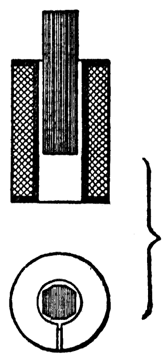


Fig. 26.

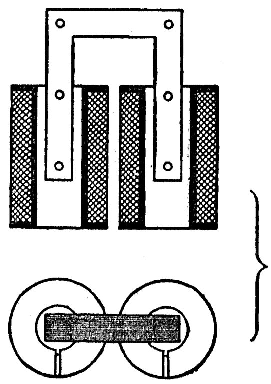


Fig. 27.

or made out of thin (0·5 mm. thick) iron sheet stampings riveted together (Figs. 26 and 27). In order to reduce eddy currents and their consequent heating effect, the iron sheets are electrically insulated by the insertion of thin paper between them. The bobbins which carry the windings are usually made of brass, and in that case are insulated with mica, paper, linen, or other insulation, and covered with a varnish capable of withstanding a considerable temperature. For alternating current the metal bobbins are slit lengthwise to prevent the circulation of eddy currents. The internal diameter of the bobbin is

1·5 to 2 cms., the available winding space about 8 × 1 cm. The bobbin winding must be such that the watts lost per coil in a lamp burning normally do not exceed about 2·5. The movable iron cores, shown in Figs. 25, 26, and 27, are made at least as long as the coil itself, and sink into it to about $\frac{2}{3}$ to $\frac{3}{4}$ of their total length in the normal position of the lamp.

With alternating current these solenoids have the disadvantage that the self-induction of the winding increases the deeper the iron core penetrates into the solenoid; hence the attraction exercised upon the iron core does not increase to the same extent, with an increased pressure across the coil as in the case with direct current. Fig. 28 shows a type of

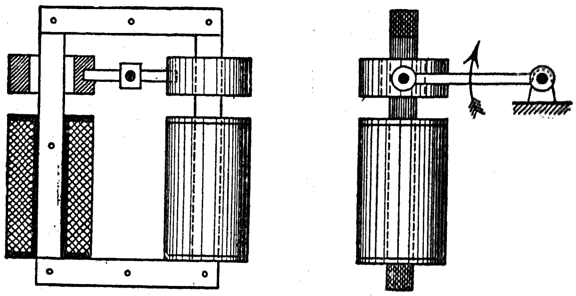


FIG. 28.

electro-magnet for alternating current (employed in lamps of the Union Electric Co.) in which the iron cores as well as the exciting coils are stationary. The movable portion which operates the lever, *i.e.* the striking mechanism, consists of aluminium rings of a comparatively large transverse section, which to a certain extent form the short-circuited secondary winding of a transformer of considerable leakage on account of the juxtaposition of the primary winding and the short-circuited secondary. In these rings large currents are induced which weaken the magnetization of the portions of the iron cores under their influence, *i.e.* increase the magnetic leakage

of the lines of force. The consequence of this is that the movable rings try to seek a weaker magnetic field, and are therefore repelled from the fixed exciting coils. Moreover, the self-induction of the exciting coils is diminished as it depends upon the position of the movable rings, the apparent reluctance of the leakage field being increased by the removal of the rings from the fixed coils.

Alternating current arc lamps with motor regulation are similarly provided with fixed horse-shoe magnets made of thin iron stampings. In these the movable portion consists of a copper or aluminium disc capable of being rotated. It is fixed between the poles of the electro-magnet, and upon it the magnets

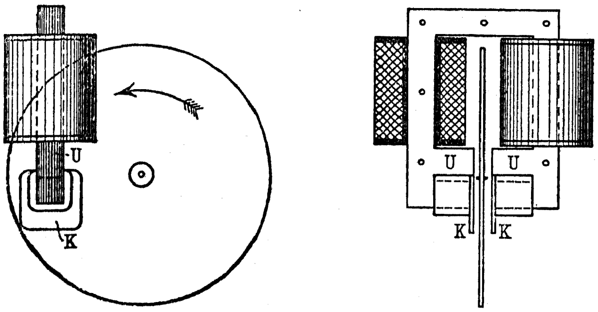


FIG. 29.

exert a torque owing to the eddy currents induced in the disc. Fig. 29 shows diagrammatically such a disc of the Allgemeine Elektrizitätsgesellschaft (A.E.G.) motor arc lamp; Fig. 30 that of the Siemens-Schuckert alternating current lamp. In the former, portions of the poles are covered by copper rings and copper plates, K (Fig. 29). The uncovered portion, U, of the pole-piece induces eddy currents in the portion of the disc directly opposite to it at a given instant, and also in the copper plates; these, being produced by the same primary magnetic field, will flow in the same direction as those on the disc. Since parallel currents flowing in the same direction attract one

another, a torque is exerted between the fixed copper plates and the movable disc, so that the uncovered portion of the disc as shown in Fig. 29 revolves towards the copper plates. In Fig. 30 the poles are not covered, but beneath each is fixed a solid piece of iron, B, which has eddy currents induced in it by some of the lines of force which leak into it. The lines of force produced by these eddy currents combine with the leakage lines and produce a resulting field, Z_2, which is out of phase with the main field, Z_1. The magnetic conditions are thus the same as exist in a 2-phase motor, and consequently the disc has a torque exerted on it. *The magnetic reluctance, and hence the*

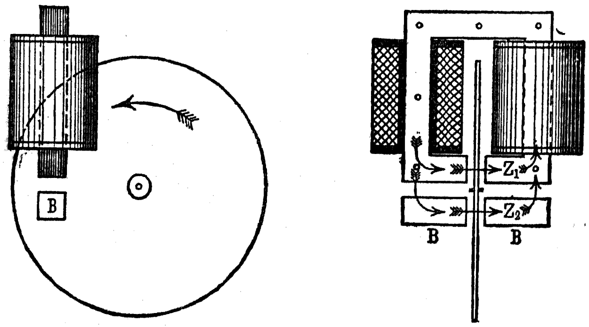


FIG. 30.

self-induction, is in both arrangements of the magnets independent of the position of the movable disc.

3. *The Lever Frame, etc.*—The frame invariably consists of brass plates fastened together, between which is a chain pulley and a wheel train which is so geared that the feed per tooth of the escapement is about 0·05 to 0·1 mm. The chain pulley is connected with the gear-wheels by the interposition of a ratchet-wheel and a pawl. The ratchet-wheel is fixed to the chain pulley, whilst the pawl and its spring are fastened to one of the gear-wheels. Hence, although the chain pulley serves to feed the carbons, it can be freely moved in the reverse direction

in order to insert new ones. Directly or indirectly connected with the lever frame is the movable part of the electro-magnet (viz. the iron plunger or armature), as well as the dashpot. Fig. 31 shows the lever frame as employed in an A.E.G. direct current lamp. Wheels and drive are made of hardened bronze, so that both wear and oxidization are slight. On the axle of the escapement wheel is fixed a centrifugal brake, the movable portions of which rub against the side plate when the rotation is too rapid. Frequently vanes are used instead of the centrifugal brake. The regulation of the lamp is not affected by these brakes, so they need not be considered in detail, but they are of importance if for any reason there is too great a distance between the carbons before switching in (*e.g.* when carbons shorter than the correct length for the lamp are inserted), as the train of wheels revolves quickly owing to the weight of the upper carbon holder or to a downward pull on the upper carbon by the operator. The sudden arrest of the wheel train when the carbons touch might otherwise bend or damage one of the parts.

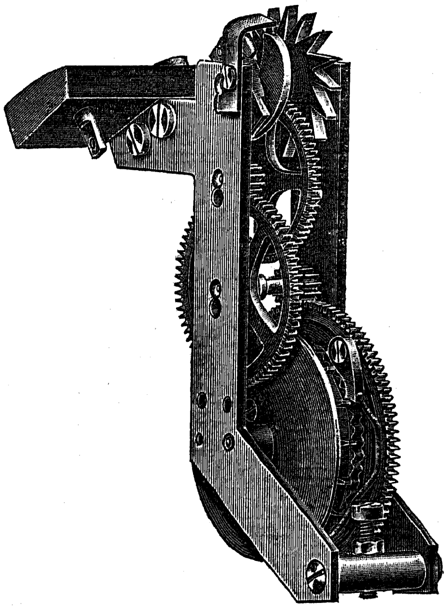


FIG. 31.

The construction of the wheel mechanism must be very exact if it is to run smoothly for years without repair; and it is especially recommended only to use well-milled pinions and

gear-wheels and to leave sufficient clearance between the wheels, since the collection of dust is unavoidable and may increase the friction so much that the weight of the upper carbon support may no longer suffice to set the wheels in motion. The axles must be carefully polished and made as light as possible. The pivots should be lubricated sparingly. For this purpose it is desirable to use an oil which does not harden or oxidize in

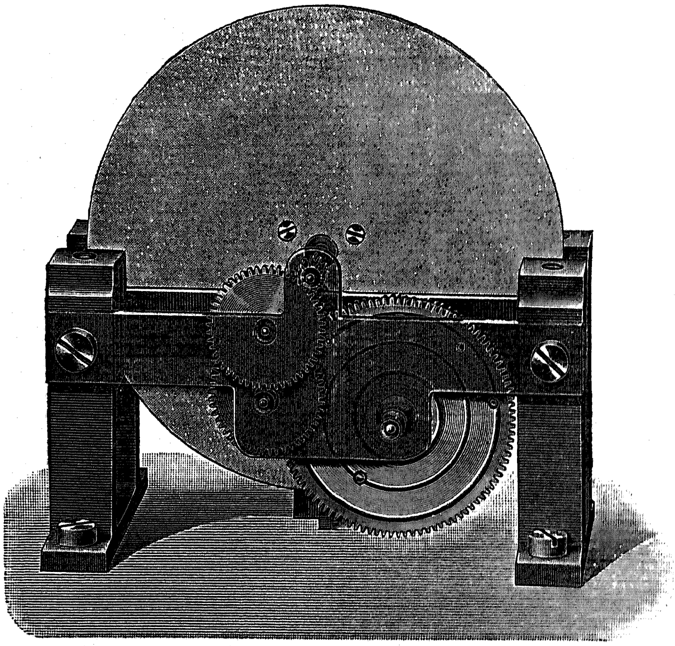


FIG. 32.

the greatly varying temperatures to which the mechanism of an arc lamp is subject. On account of these great temperature variations, the pivots must be such that a contraction or expansion does not produce a jambing of the axles.

Fig. 32 shows a wheel mechanism with an aluminium disc for an A.E.G. alternating current motor arc lamp. Escapement

and dashpot are here superfluous, because the drive is not effected by a pull upon the chain-wheel and the arc is not struck by means of a swinging lever movement, but they follow as the result of the torque on the disc in either direction. The movement of the disc is transmitted to the chain pulley by a train of wheels. Hence in simplicity and reliability this construction is superior to the previous one; especially is the deposit of dust on the wheels of less influence, because the drive is direct upon the quickly (relatively to the chain pulley) rotating shaft, and because *the power of the drive increases with an increased inequality of the electrical conditions.* It is important in motor lamps to bring the magnetic pull in unison with the inertia of the rotating disc and the train of wheels, so that an inadmissible oscillation or swinging movement of the disc may not occur with a varying main pressure.

4. *The Detent.*—The detent is usually made of hardened steel, and is screwed to a lever, and adjustable (Fig. 33). The lever is usually hinged to a pillar mounted in the base plate, and is connected with a weak spring or a weight in order that it may have a steady motion. The purpose of the hinge is to render a striking of the arc still possible even if the edge of an escapement tooth comes into contact with the edge of the detent, since in that case the detent participates in the swinging movement of the lever frame. It may be mentioned here that the escapement or brake need not have teeth, and the arrest as shown in Fig. 14 may be operated by friction with a suitably modified detent. In the latter case the regulation of the lamp is sometimes even more exact than in the lamps above described. The friction brake, however, has the disadvantage that it is influenced by a shaking of the lamp.

5. *Regulating Spring and Lever.*—The regulating or counteracting spring (Fig. 34) tends, especially in shunt arc lamps, to oppose the swinging movement of the lever frame exerted by the electro-magnet. At one end it is attached to the swinging

clockwork frame or the movable iron plunger or armature, and at the other end to a *regulating lever* as in the figure. The spring is made of hardened steel, and it is desirable to temper it after it is fixed so that its tension may not be further altered under the influence of the lamp temperature. The diameter of the spring, the number of the coils, and the tensile strength of the wire must be proportioned to the power of attraction of the magnet. The more coils the spring has, with a given magnet construction, the higher will be the P.D. across the

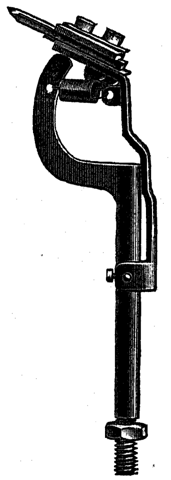


FIG. 33.

FIG. 34.

arc immediately after switching in, because then, with a given movement of the clockwork lever frame in the direction for the striking of the arc, the tension of the spring alters relatively less than if the spring had fewer coils. But this alteration in the tension of the spring must be in a certain proportion to the alteration in the attraction of the core or armature of the electro-magnet, because either the return of the lever frame in the direction of the feed would only take place with an abnormal P.D. across the arc, and thus in the event of a

disturbance through loose particles of carbon a more frequent flaring up of the arc takes place, or the arc would be struck with too low a P.D. across the arc with a consequent unnecessarily large striking current.

These considerations, of course, only apply to shunt arc lamps. To stretch the spring in order to obtain a certain arc length, the regulating lever (Fig. 34) is employed. It is usually fixed in the base plate in such a way that it may be adjusted, and is held by the spring against an adjustment screw.

6. *The Dashpot.*—The air dashpot consists almost invariably of a brass cylinder, about 20 to 30 mm. diameter, attached to the lever frame, in which works a brass piston secured to the base plate (Fig. 35). Its purpose is to prevent the sudden movement of the lever frame, which would otherwise occur with the considerable current fluctuation as produced in the striking of the arc. With the delay which the dashpot causes in the separation of the carbons after contact, a greater heating of the carbons takes place, and consequently an easier striking of the arc. Without the damping arrangement it is scarcely possible to strike an arc in lamps with such a swinging lever frame, especially with partially consumed carbons, on which the tips are already formed. The damping must have a definite relation to the pull of the magnet. It depends (with a given movement of the lever frame and a sudden motion of the same) upon the difference in pressure between the air within the cylinder and the outer air, as well as upon the size of the piston. The damping is therefore greater, the larger the diameter of the piston, the greater the change in volume of the air in the cylinder, and the deeper the piston plunges into the cylinder. The cylinder and piston must be perfectly round, and the contact surface well polished. The longer the piston the more easily it will move with a given amount of damping The piston is provided with grooves, into which any possible

dust may settle, and friction is thereby prevented. Lubricants must not be used.

7. *The Guide Frame.*—The guide frame usually consists of two pinchbeck tubes (Fig. 36), or else solid brass rods (Fig. 37),

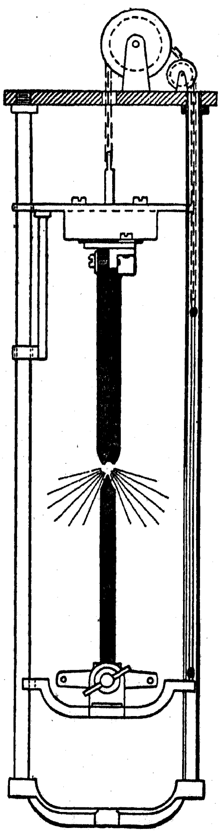


Fig. 36.

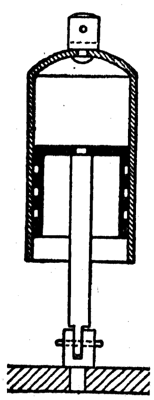


Fig. 35.

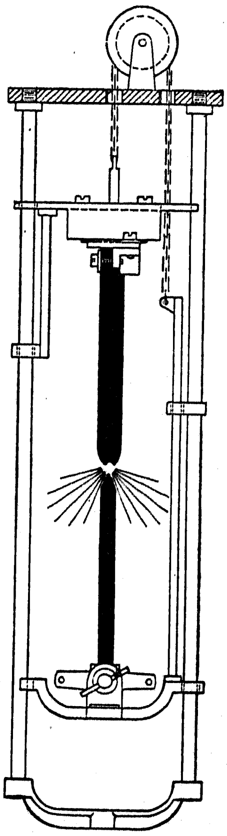


Fig. 37.

which are fastened to the base plate and connected at the bottom by a cast-iron or brass cross-piece, which keeps them parallel. Their length depends upon the size of the carbons. The diameter of the tubes is usually 10 to 13 mm., that of the solid rods about 9 to 10 mm.

8. *The Upper and Lower Carbon Holders.*—These serve to maintain a central position of the carbons, and with the guide tubes, are usually constructed as in Fig. 36. The guide tubes must be slit, in order to carry the carbon supports according to the length of carbons used. A disadvantage in the use of tubes is that they accumulate dirt and rust internally, owing to this slit. Hence the guide rods within the tubes must have ample room inside, and are only provided at the top and bottom with guides. If solid rods and the arrangement shown in Fig. 37 are employed, it is easy to keep everything clean and smooth.

The ends of the holders are attached to a chain or flexible

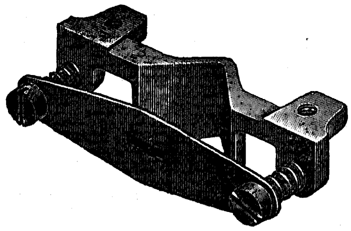


FIG. 38.

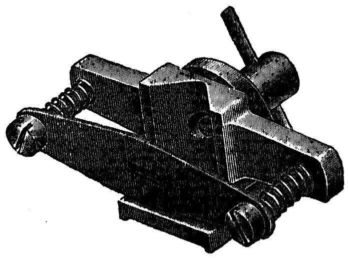


FIG. 39.

copper wire, which is passed over the chain pulley in the swinging lever frame. In addition to this, the upper holder (except in A.C. motor lamps) is weighted, usually with cast iron, to such an extent that it preponderates over the lower holder by about $\frac{2}{3}$ to 1 lb. (300 to 500 gms.), and thus sets the train of wheels in motion. Copper wire has the advantage over a chain that it permits of a smaller hole in the base plate, but, as against this, it readily corrodes and becomes stiff and brittle.

9. *Carbon Clamps.*—Clamps are used to secure contact with the carbons. They are usually constructed of split brass sleeves (see page 60) to admit of carbons of a fixed size. In other clamps the contact surface is sometimes V-shaped, and a steel spring is employed to secure an elastic grip, and will admit

carbons of different diameters. Fig. 38 shows an upper, and Figs. 39 and 40, a lower carbon clamp. The latter clamp

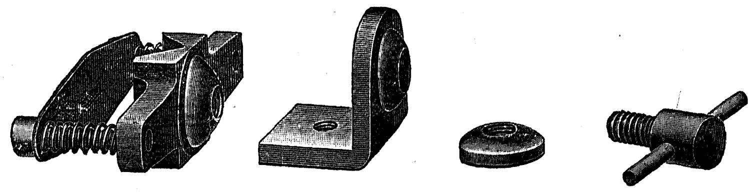


FIG. 40.

is so adjustable that a satisfactory adjustment is possible, even with crooked carbons. The clamps are usually made of bronze. The depth of the V-shaped part of the clamp is about $\frac{4}{5}$ to 1 in. for currents of 6 to 15 amps. The clamp without a spring attachment is unsatisfactory, owing to the unequal expansion of the metal and carbon, especially with alternating current, and often results in the carbons falling out.

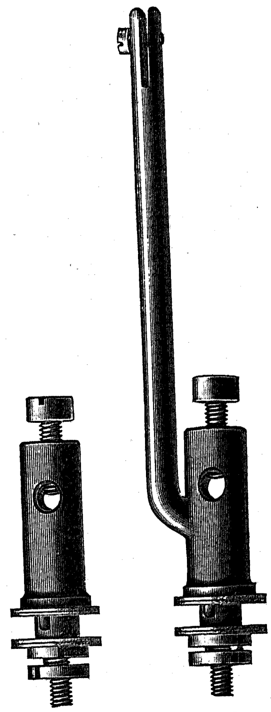


FIG. 41. FIG. 42.

Both must be capable of adjustment on their holders in order to facilitate the placing of carbons of different sizes in a central position. One holder, at least, must be insulated.

10. *Terminals.* — Terminals are usually constructed as in Fig. 41 or 42. One is fixed in the base plate, either with or without insulation. The current is led from the terminals or from the electro-magnet winding to the movable carbon holders by means of flexible copper wire, which is either insulated with glass beads or coiled spirally on a special rod,

so that contact between parts of opposite polarity is guarded against.

11. *Reflectors and Economisers.*—Alternating current lamps require a reflector above the arc, because the lower carbon sends upwards the same stream of light as the upper carbon sends downwards. For this purpose a cross-piece is fixed to the guide supports, which may serve partly as a carbon support and partly to secure the reflector. Fig. 43 shows such a cross-piece with a reflector as in the alternating current lamp in Fig. 61.

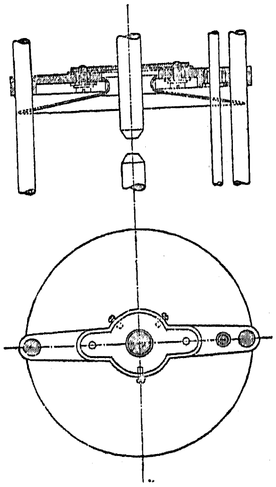


FIG. 43.

The cross-piece is attached to the guide frame, and insulated therefrom with mica, and also has a similarly insulated plate acting as a guide-plate for the carbon. The iron

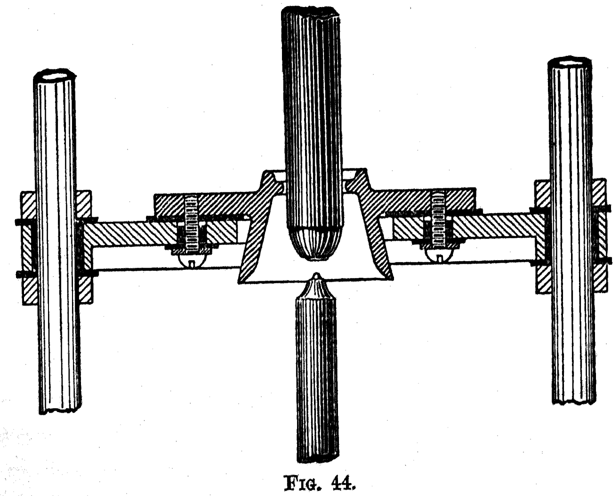


FIG. 44.

enamelled reflector fixed to it is bent outwards at the top and

fastened to the cross-piece by screws. The inner surface of the reflector is enamelled white, so that the reflection of light is as large as possible. The shape of the reflector is usually that of a truncated cone, but it may also be made curved. In the latter case, the light is concentrated and the illumination beneath the lamp is more intense within a small radius. But the exact shape of the reflector does not appear to be of paramount importance, since the distribution of the light mainly depends upon the power of diffusion of the globe. The use of a reflector over the arc has little appreciable value with direct current, because the distribution of light of the lower negative carbon is only slight, and in the crater of the upper carbon we have a natural reflector already to hand. It is possible, however, to employ an economizer over the arc instead of a reflector (Fig. 44). The economizer forms a closed hollow space above the arc, the air in which is lacking in oxygen, whereby the consumption, especially of the upper carbon, is lessened, and a longer burning is obtainable. In spite of this advantage, the economizer is little used with ordinary direct-current lamps, because under certain conditions it is easily disturbed by the arc, *e.g.* when bad carbons are used, or when a draught (caused by faulty globes, and thus preventing the formation of carbon monoxide) is occasioned; and also, on account of the paucity of oxygen at the carbon tips, the intensity of the light appears to be less with an economizer than without.

12. *The Casing.*—The casing in which the whole lamp mechanism is enclosed usually consists of an upper part, which contains the regulating mechanism proper, and a lower part, detachable for the purpose of inserting new carbons, to which the glass globe is attached. The upper portion, again, consists of a suitable flanged cast-iron ring, to which the base plate (insulated if it carries current) is screwed. On top of the ring a metal cover is fitted as closely as possible. The close fitting of the latter is very important, as it reduces to a minimum the

access of air to the regulating mechanism, and keeps out all dust. To the ring is also attached the hanger carrying the porcelain insulator. The hanger is made to fold back, in order that the cover may be readily removed and the mechanism readjusted. In this ring are also fixed the porcelain bushes through which the leads are introduced. These bushes must be so arranged and of such a shape that rain cannot find its way into the lamp.

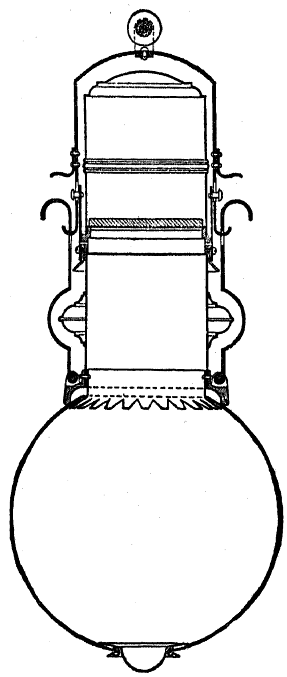


FIG. 45.

The lower portion of the lamp consists of a metal cylinder with a suitable stamping or casting at its lower rim, to which the globe is attached. The latter is usually attached by a wire netting (copper wire of about 1 mm. diameter) with the assistance of a metal ring fitted to the lower end of the globe. In order to secure the globe still further, especially if the net attachment is not desired, an indented metal strip may be attached to the bottom of the cylinder, its teeth being bent outwards, so that it grips the globe inside.

On the cylinder are also placed the hooks necessary for attaching it to the upper portion of the casing. This attachment, whilst offering the simplest possible manipulation, must effect an absolutely safe and rigid connection, and it must be sufficiently rigid to prevent the lamp swinging against its support in windy weather. In Fig. 45 (A.E.G. construction) this is attained by the hanger being hooked at its lower ends and provided at its pivots with long (deep) slots. In lifting up the lower casing

the upper rim of the metal cylinder presses against the projecting ring, which causes the latter, together with the lamp mechanism, to be lifted up through the medium of pins (pivots) in the long slots of the hanger until the lower hooks engage with the hooked ends of the upper hanger. Projecting pieces fixed to the hanger facilitate the hooking on.

Another modification—a rigid connection between the upper and lower portions of the casing to effect an easier manipulation—

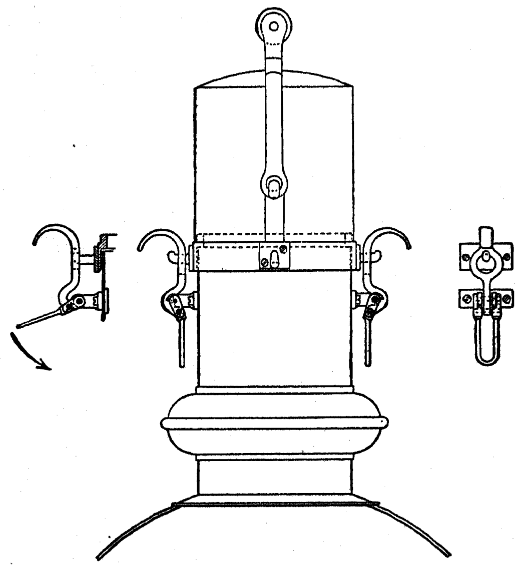


FIG. 46.

is effected by a crank motion of the lower hook. Fig. 46 shows the scheme in the Union Electric Co. lamp, and Fig. 47 in the Siemens-Schuckert lamp. In both cases the lower perforated hooks engage in the projecting lugs or hooks by a downward excentric movement of a lever fixed to the lower casing. In order that it could unhook of its own accord the axis of rotation of the hook would have to come from below the crank pivot until, by a movement of the lever both outwards and upwards, the

hook pivot lay outside the line joining the crank pivot and the point of support of the hook (*i.e.* the projecting lug) (see Fig. 46). In Fig. 47 the hook, by being bent into the shape shown, has some spring, so that slight inequalities in execution are not of serious consequence.

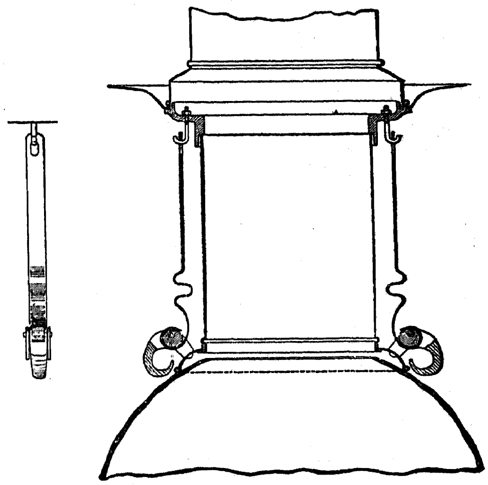


FIG. 47.

The lamp casing must admit of a certain constant flow of air to the arc, since the carbon tips would not be suitably formed (see p. 3) and would tend to "mushroom," thereby obscuring the light rays. Hence, according to the construction of the lower portion, it sometimes becomes necessary to introduce special ventilation inlets. These are situated close beneath the base plate, so that the warm, ash-laden air beneath it obtains an outlet. Fresh air is partly introduced in the same way, partly between the globe and ring where they do not fit exactly, and partly by means of an ash-pit. The latter is made either of glass, zinc, or pinchbeck, and serves to close the lower opening of the globe. Frequently the ash-pit is provided with special vents, closed with a netting of a fine mesh, in order to prevent sparks from falling out. The ash-pit must be so arranged that it scarcely closes the lower opening of the globe and is not dislodged by vibration. Its function is partly to catch sparks so that they may not crack the globe, and partly to facilitate the cleaning of the inside of the globe.

The globes are almost exclusively made of opal or alabaster glass about 4 to 6 mm. thick. The thickness of the opal or alabaster covering must be such as to secure the most uniform illumination (which cannot be obtained without such a globe by the exposed arc, owing to the irregular distribution of its light) with the least possible loss of light due to absorption. In the globes used in practice this loss usually amounts to 20 to 30 per cent.

With opal glass the arc appears as a point of light; with alabaster glass more as a flame. The power of dispersion of the latter is therefore greater, and its application for internal lighting with bright walls and ceilings correspondingly advantageous. For outdoor lighting purposes, on the other hand, the opal globe is generally chosen. The same distribution of the rays as with the alabaster globe (together with a smaller loss of light) may be obtained by globes with a matt surface, produced by sand blast or etching, provided the grain be free enough. These globes, however, easily become dirty on their rough surface so that they appear unsightly, and the loss of light soon increases. Clear glass globes are often used in railway yards with alternating current lamps, partly because the distribution of light with the alternating current arc with a suitable reflector placed over it, is somewhat more uniform. Hence the more transparent opal and alabaster globes are often chosen for use with alternating current arc lamps. On the other hand, the illumination on the ground with alternating current lamps of equal consumption is appreciably less than with direct current lamps. The globe may be either spherical or pear-shaped.

The whole regulating mechanism must be so fitted within the casing that the latter shall carry no current.

B. DESCRIPTION OF LAMPS FOR DIRECT LIGHTING.

Fig. 48 shows a direct current shunt arc lamp of the A.E.G. for an average P.D. of 40 volts across the arc, and for series connection of two lamps on 110 volts supply, and four or five lamps in series across 220 volt mains, a steadying resistance being required in each case.

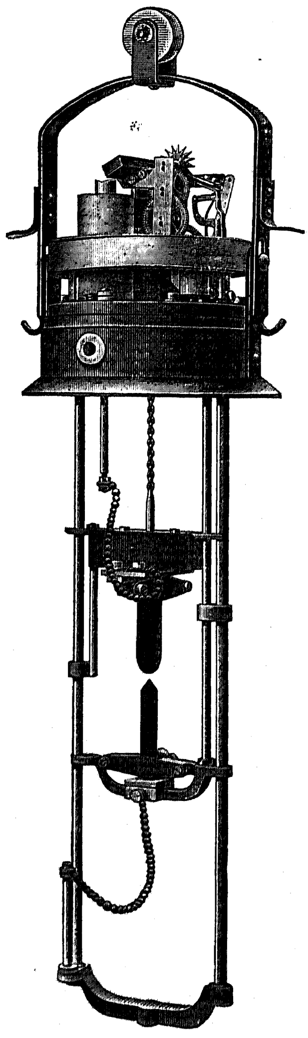


FIG. 48.

The mechanism has already been explained on p. 23. It is noteworthy that in order to reduce the temperature error which is caused by the difference of the regulating P.D. of the arc in a cold and a hot lamp, a resistance is connected in series with the winding (copper wire) of the electro-magnet. This is wound on a metal ring, the coil surface being near to the lamp casing in order that it may be cooled. In the diagrammatic sketch of these lamps (Fig. 49) it may also be noted that a small portion of this resistance, R, is short-circuited during the contact of the escapement-wheel and the detent, but is inserted as soon as a tooth of the escapement-wheel disengages from the detent during the feed. Hereby an artificial weakening of the shunt magnet occurs in passing from tooth to tooth, so that the influence of the hysteresis of the magnet, as well as of the

friction, is counterbalanced and an exact regulation is obtained. Another method of eliminating the temperature error is to be found in the alteration of the tension of the spring or in the alteration of the position of the detent (according to the kind of lamp) by means of *temperature compensators* as employed by the firm of Körting and Mathiesen, Ltd. In principle, the compensator depends upon the expansion, with increased temperature, of metal tubes in the interior of the lamp. This

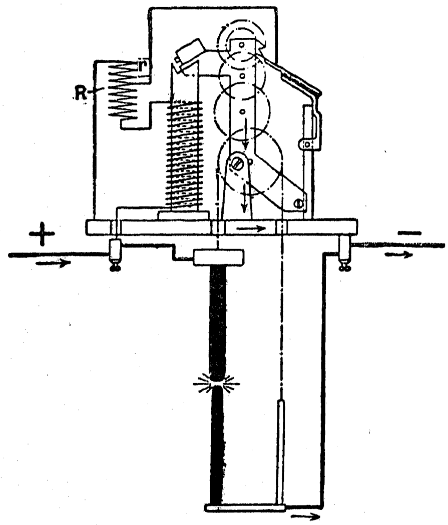


FIG. 49.

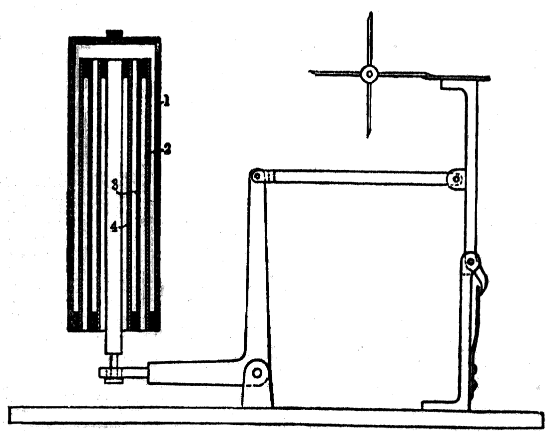


FIG. 50.

expansion is communicated by a bent lever, either with the lever frame and hence the 'scape wheel, or the detent, in such a manner that the P.D. for the lamp remains constant in spite of the increased temperature of the magnet winding and the consequent weakening of the electro-magnet. In order to secure a sufficient increase in length with tubes of small size, several, or alternate, iron and zinc tubes are used and built up so that the elongations of the more readily expansive zinc are added (see Fig. 50). 1 and 3 are iron tubes, 2 and 4 are zinc. The iron tube 1 is attached to a support in the base plate.

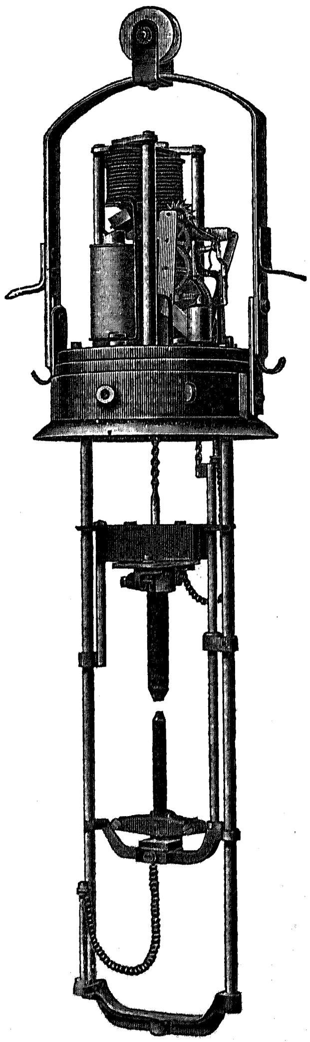


FIG. 51.

Fig. 51 is a direct-current, differential arc lamp of the A.E.G. for about 40 volts P.D. across the arc. Two to three of these lamps are used in series for 110 volts, or five to six for 220 volts or for a pressure of 37 to 55 volts per lamp. The construction and mechanism have already been described on p. 31. This lamp differs in construction from the shunt arc lamps only in the addition of the series electro-magnet, in the employment of a stronger air dashpot with a larger stroke, in the use of a weaker controlling spring, and in the elimination of the special

frame for the resistance for the shunt coils. The temperature error of the shunt coils has not such a great influence on the P.D. across the arc in a differential lamp, because to the greater attraction of the shunt in the cold condition of the lamp there is a somewhat greater lamp current, which in turn strengthens the attraction of the opposing series electro-magnet. Therefore the temperature error is, with similar conditions in the shunt

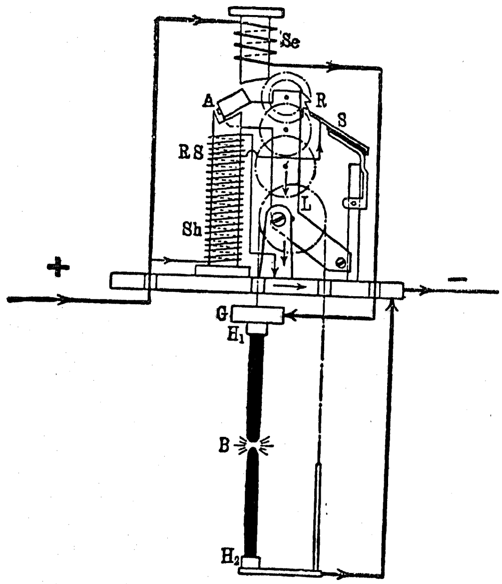


Fig. 52.

winding, only half as great in differential lamps as in shunt lamps. Hence, in differential lamps, the use of a special resistance in the shunt coil circuit may be dispensed with, and the winding may consist simply of insulated copper wire. In the above lamp, as shown in Fig. 52, a portion of the winding of the coil Sh is wound with resistance wire, and a portion of the latter spirals RS is short-circuited by the teeth of the escapement-wheel R and the detent or stop S, as in the case of shunt

lamps. The regulation of the lamp is therefore extremely exact. Naturally the whole electrical behaviour of the lamp depends on the form of the pole pieces of the electro-magnets. In the lamps shown these pole pieces are so constructed that the armature approaches tangentially to their pole-faces. By this means it is possible to alter at will the pull of the electro-magnets with respect to the position of the armature. For shunt lamps these conditions are so arranged that for the extreme position of the armature against the detent S, a P.D. across the arc of about 3 to 5 volts below the normal P.D. maintains the equilibrium of the opposing or regulating spring. If the pole pieces are so formed that the normal tension of the spring maintains an equilibrium for every position of the armature (possible with a suitable form of the pole pieces and taking account of the altering tension of the opposing spring), or if the P.D. is higher in the extreme position than in the normal position, then the disadvantage arises that the lamp flares up too readily with every disturbance of the arc through loose particles of carbon, and another disadvantage is that the striking of the arc with partially consumed carbons is only effected after much jerking of the carbons. The magnets in A.E.G. lamps are movable horizontally (through the provision of slots), whereby an adjustment of the pull is possible for different lamp currents without altering the windings.

Fig. 53 is a Johnson & Phillips differential lamp of the *brake-wheel* type. The electro-magnetic control consists of a series solenoid, Se, and a shunt solenoid, Sh, actuating respectively the cores C, C (Fig. 54). These solenoid cores are pivoted to opposite ends of a balance arm, R′, which is centrally pivoted at P. The brake gear consists of a brake-wheel, Bw, having a rim on which rest two brake blocks, Bb, one inside the rim and the other outside the rim. These brake blocks are so pivoted on a brake lever, Bl, that when the lever is horizontal the wheel can slip freely through the brake blocks, but a slight tilting of the

lever causes Bb to grip the rim of Bw. One end of Bl is connected to the balance arm R′, and the other end rests freely on a support S.

The carbons are gripped in split tube holders, H_1 and H_2,

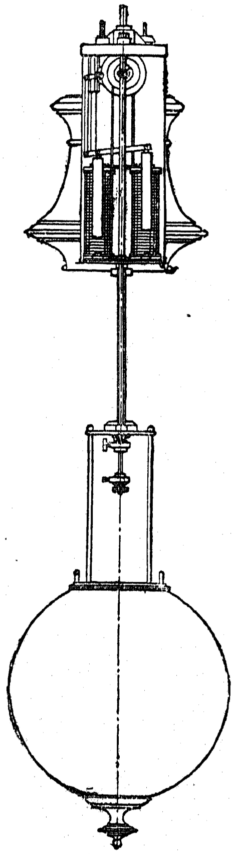


Fig. 53.

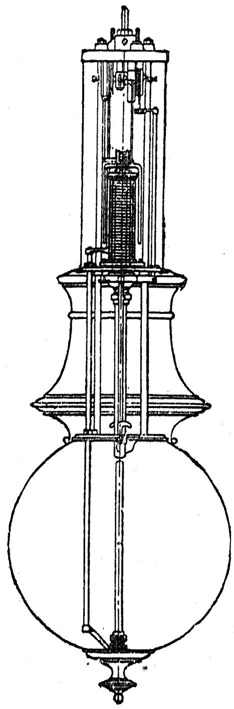


Fig. 53A.

attached to sliding rods, which ensure their movement being strictly along the axis of the carbons. These rods are connected by means of flexible, braided copper tape to two wheels, both mounted on the same shaft as the brake-wheel (Fig. 54), but are

insulated from each other. The connections are so arranged that as one carbon descends the other ascends, thus maintaining the arc always in the same place. The positive carbon holder is much heavier than the negative, so that the carbons approach each other by gravity. The position of Bl and the carbons touching shown in Fig. 54, is the normal state before the switching-in of the lamp.

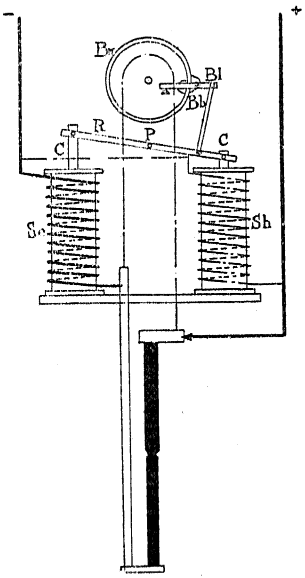


FIG. 54.

When current is supplied to the lamp the series core is powerfully magnetized and pulled into its solenoid, Se; this tilts the balance arm and causes Bb to grip the brake-wheel, and causes it (Bw) to rotate slightly, thus striking the arc.

As the carbons burn away and arc P.D. increases, the shunt solenoid gets gradually more powerful and causes Bl to assume a position in which the brake-wheel can slip back a little owing to the greater weight of the positive carbon holder, thus shortening the arc and weakening the shunt solenoid. An air dashpot prevents too rapid a motion of the cores and brake system. The action of the feed is fairly continuous. Fig. 53 shows the lamp closed, and Fig. 53A another view of the same, opened for trimming.

Fig. 55 shows a twin arc lamp of the same type as in Fig. 48 for direct current. It consists of two independent mechanisms with a double set of carbons, constructed within the same casing. This lamp was the outcome of an increase of the supply pressure which had for its object a diminution of the C^2R lead losses. For example, in many towns the mains pressure has been

increased from 110 volts to 220 volts. This object frequently conflicts with the number of lamps required for a certain purpose —as, for instance, for tradesmen needing only two ordinary single lamps. Since transforming to the lower pressure could not be entertained for such and similarly small lighting purposes, on account of the expenses of transformation and attendance, it becomes necessary to employ the high voltage enclosed arc lamps, which burn with about double the P.D. of the ordinary open arc lamp. Owing to the relatively smaller illumination and the constant wandering of the arc, these lamps have not met with general approval in Europe, in spite of the advantage of prolonged burning which they give with a single pair of carbons, at any rate, for street lighting; though in America it has driven out the open arc for both indoor illumination and street lighting. In England, at the present time, we may say fairly that the most popular type of arc lamp for indoor illumination is the single globe enclosed (see p. 110); and the flame arc lamp is rapidly superseding the ordinary open and enclosed lamps for external lighting. In Germany especially, it was the above-mentioned

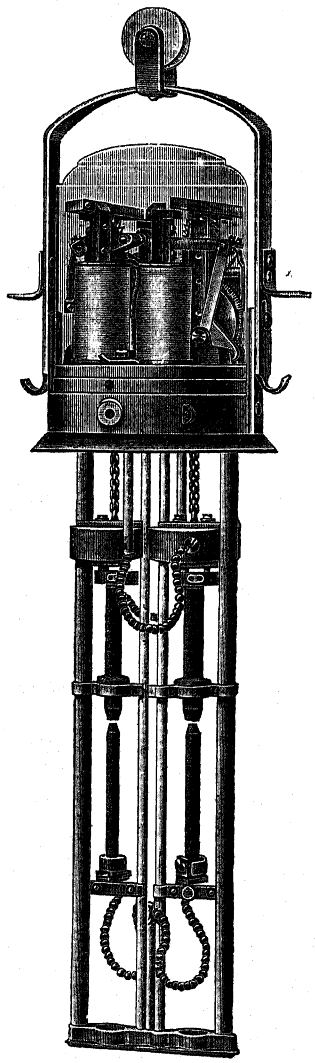


Fig. 55.

disapproval which brought about the construction of the twin open arc lamp.

Electrically, the two mechanisms and the two sets of carbons are, in this case, connected in series; and mechanically, they work independently of one another. Both arcs are struck simultaneously and are maintained with about half the current

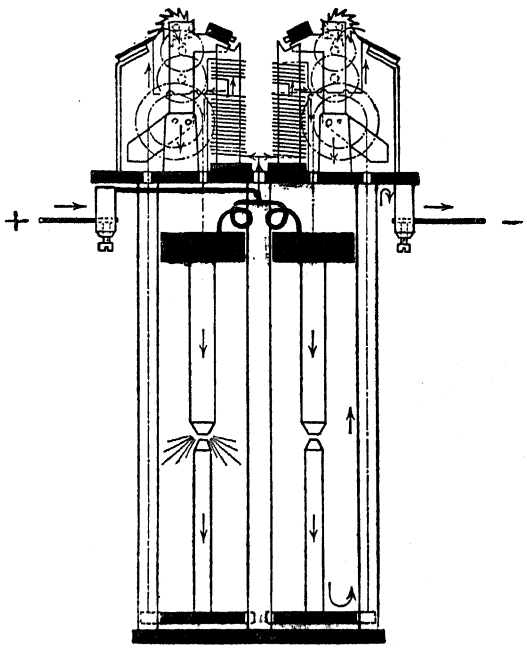


FIG. 56.

necessary in a single lamp of equal candle-power. The efficiency of such a lamp is, on account of the decreasing efficiency of the arc with smaller currents,* somewhat less than that of single lamps of equal consumption, though still somewhat greater than that of the enclosed arc lamp. Fig. 56 shows a twin shunt arc lamp, and Fig. 57 a twin differential arc lamp, in

* See p. 123.

both of which, the arcs are in series. The terminal pressure of these lamps is about 80 volts. With a resistance they can be burned singly on 100 volts, or with two lamps in series on 220 volts supply.

If it is desired to burn the lamp for a longer period with only one renewal of the carbons, these lamps can be con-

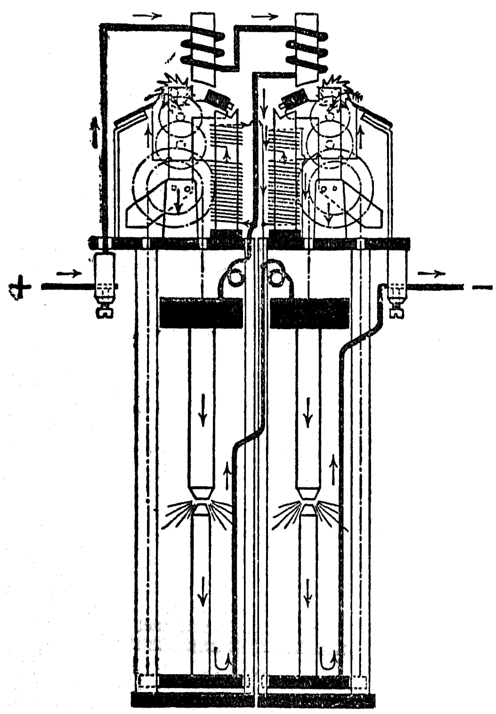


Fig. 57.

nected so that the two pairs of carbons burn consecutively; in which case the lamp is virtually a single lamp with prolonged burning. This arrangement is more generally used in the twin lamp for street lighting in this country. The regulating mechanisms and carbons are connected in parallel, and the terminal pressure of the lamp then corresponds only to

the P.D. across one arc. Fig. 58 shows the connection of a shunt lamp for this purpose, and Fig. 59 that of a differential lamp. In the latter lamp the main current passes (on entering the lamp) from one terminal to the series coils of both mechanisms in series, and then passes to one or other of the sets of carbons, and thence to the other lamp terminal. Both the

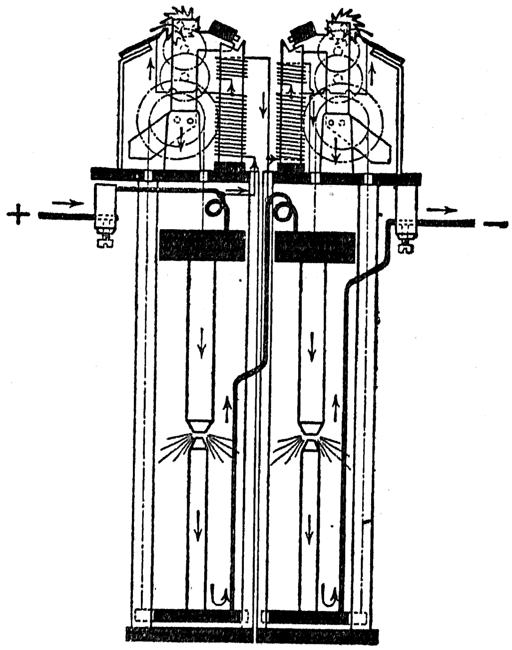


FIG. 58.

shunt coils are connected in parallel with the arc. Current thus passes through all the coils, although for the time being only one arc is struck. Hence the lamp consumes a few more watts than a single lamp. On the other hand, there is a greater certainty of action with the above connection than if an automatic switch inserted the coils of the second pair of carbons after the first pair burnt out. In the case considered the

burning pair is so adjusted with normal current that the release of its escapement-wheel (*i.e.* the feed) only occurs with about 1 to 2 volts higher P.D. across the arc than the P.D. across the other set. Since the same main current flows through both the

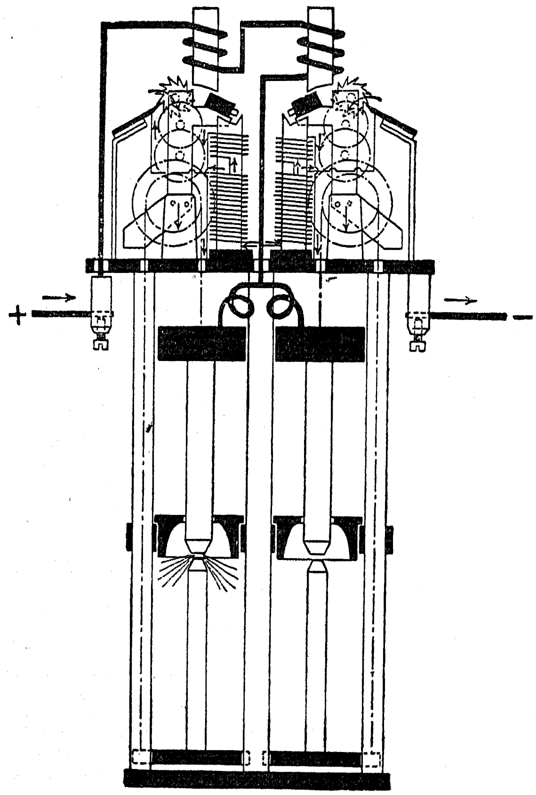


FIG. 59.

series coils, and since both the shunt coils have the same voltage, the carbons belonging to the mechanism adjusted for the higher P.D. are kept apart until the other pair (for a lower P.D.) burn out. When the holders reach their extreme positions, the length of the arc of the burning pair increases through

consumption of the carbons; thus the P.D. across the arc becomes greater until the other mechanism controlling the second pair of carbons is released. In consequence of the short circuit, due to the striking of the second arc, the first is extinguished and the

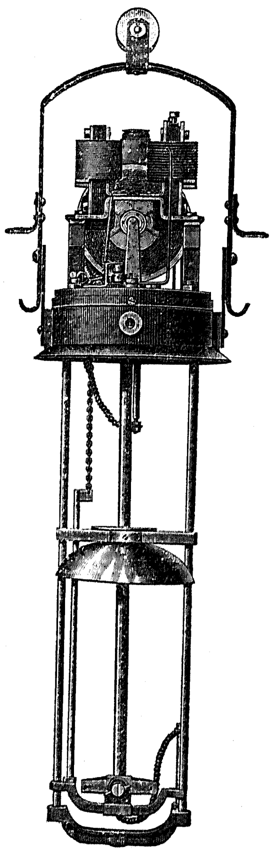


FIG. 60.

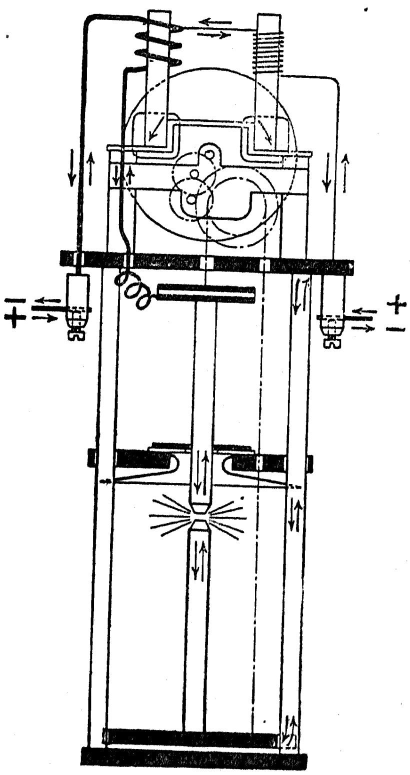


FIG. 61.

consumption and feed of the second pair begin. The two arcs need not require the above-mentioned (constant) difference in P.D. for their regulation. By the choice of pole pieces the adjustment may be so arranged, that at the first attraction the

armature of one mechanism requires a somewhat higher P.D. across the arc, though afterwards the release follows with equal P.Ds. across both arcs. The connections and mechanisms of shunt lamps are, with the omission of the series coil and the substitution for it of suitable springs or weights, the same.

Fig. 60 is an A.E.G. alternating current motor arc lamp. Between the series and the shunt magnets a metal disc capable of rotation is inserted. The pole pieces are partly covered with

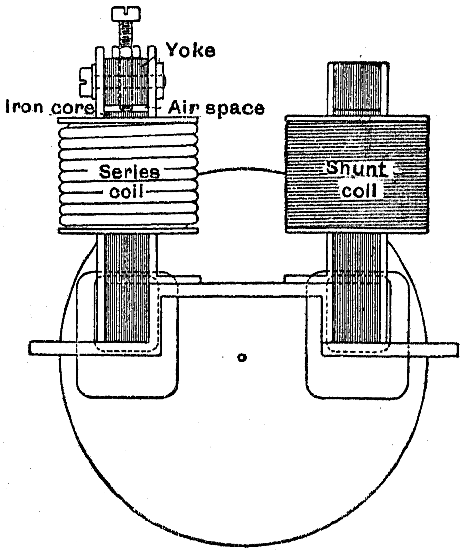


FIG. 62.

fixed copper plates or shoes. In the latter and the metal disc the magnets induce eddy currents, which produce a torque on the movable disc. As shown in Fig. 61, the magnets are so arranged as to produce opposite torques. The effect of the series magnet is to strike the arc; whereas that of the shunt magnet is to produce a feed. For a given lamp current and P.D. across the arc, the lamp may be adjusted to give equal and opposite torques by selecting the number of turns or by varying the air gap in the magnetic circuit of the

series magnet. The latter alteration is effected by means of the adjustable yoke shown in Fig. 62. The movement of the metal disc is transmitted to the carbon holder by gear-wheels and a chain pulley. A lengthening or a shortening of the arc occurs according to the way in which the equilibrium of the torques is disturbed. The lamp is therefore regulated continuously by the resistance of the arc, and not periodically as is the case in lamps provided with a clockwork escapement. Since the motor lamp is not affected in its working by any heating, as lamps with a swinging lever frame are, it has the advantage that immediately after the striking of the arc the electrical conditions become normal.

All the lamps heretofore described are only suited for use with ordinary pure carbons, and cannot be employed to advantage with chemically treated carbons or other electrodes.

C. SIZES OF CARBONS.

The following tables give the sizes and lamp pressures for pure carbons. For direct current the positive carbons are cored and the negative carbons solid, and in the case of alternating current both carbons are cored. The consumption of the positive carbon with direct current is greater than that of the negative carbon. In order to secure an equal consumption, the former is chosen with a correspondingly greater diameter.

SIZES OF CARBONS AND LAMP PRESSURES FOR TWO D.C. ARC LAMPS IN SERIES ON 110 VOLTS, OR FOUR TO FIVE IN SERIES ON 220 VOLTS, OR FOR MORE IN SERIES WITH ABOUT 45 TO 50 VOLTS PER LAMP.

TABLE I.

Current	2	3	$4\frac{1}{2}$	6	8	10	12	15	Amperes
Lamp pressure	36	37	38	39	40	41	42	43	Volts
Cored carbon	8	11	13	15	16	18	20	20	Diameter in mm.
Solid carbon	5	7	8	9	10	12	13	14	Diameter in mm.

Sizes of Carbons and Lamp Pressures for Three D.C. Lamps in Series on 110 Volts, or Six Lamps in Series for 220 Volts, or for more in Series with about 37 to 40 Volts per Lamp.

TABLE II.

Current	$4\frac{1}{2}$	6	8	9–10	12	Amperes
Lamp pressure ...	35	35	35	35	35	Volts
Cored carbon ...	11	13	14	16	18	Diameter in mm.
Solid carbon ...	7	8	9	10	11	Diameter in mm.

The length of each carbon is usually 8, 10, or 12 inches (200, 250 to 290, or 325 mm.). They burn for the corresponding periods of 8 to 12, 12 to 18, or 15 to 20 hours, leaving a remainder of 40 to 50 mm. ($1\frac{1}{2}$ to 2 inches approximately) length for open arcs. With the smaller currents they burn for a shorter time than with a greater current, so that for a medium current strength of 8 amps., with the given lengths, they would burn for about 10, 14, 16, or 18 hours. In interiors they burn on the average 1 to 2 hours longer, owing to decreased air circulation. In lamps provided with an economiser over the arc, the positive carbon is usually 1 mm. less in diameter. Positive carbons of inferior quality (producing more ash) require a somewhat thinner (solid) negative carbon, but these, as a rule, are only adapted for lamps which burn with a pressure of at least 50 volts.

Sizes of Carbons and Lamp Pressures for an A.C. Lamp for 40 Volts Supply, for Two Lamps with 72 to 80 Volts Supply, for Three on 105 to 120 Volts, or for Six on 200 to 220 Volts, or for more in Series with a Terminal Pressure of about 36 Volts per Lamp and an Alternating Current with a Sine Wave Form.

TABLE III.

Current	8	10	12	15	20	Amperes
Lamp pressure ...	28–30	29–31	29–31	29–31	31–33	Volts
Cored carbons (upper and lower)	11	12	13	14	16	Diameter in mm.

The periods of burning in this table for pure carbons for the respective lengths, 8, 10, and 12 inches per carbon for exterior lighting are 8 to 9, 12 to 14, and 15 to 16 hours.

D. LAMPS FOR DIFFUSED LIGHT (INDIRECT LIGHTING).

By means of a suitable modification of the lamp casing and globe, it is possible to obtain with the above lamps a strongly diffused or shadowless illumination. Such lamps are suitable for lighting purposes in drawing offices, spinning mills, engraving works, etc.

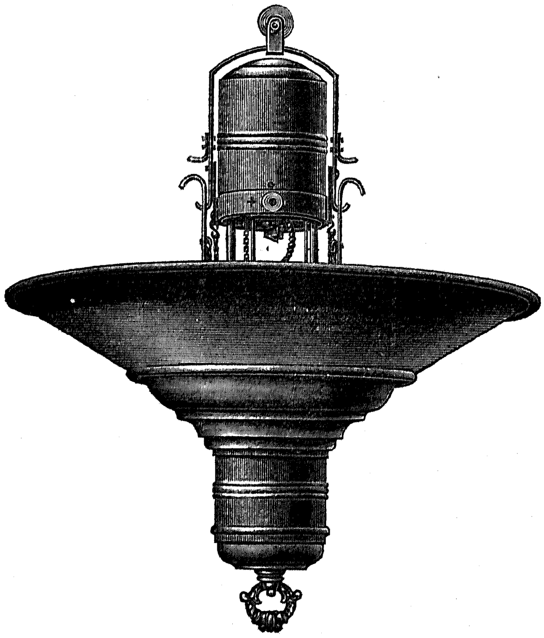


FIG. 63.

The simplest and most economical construction, in so far as lighting with direct current is concerned, is that in which the

lower carbon is the positive. These are the so-called "inverted" arc lamps, in which the crater casts its rays upwards on to the ceiling. The latter then serves, in rooms from 11 to 16 feet (3·5 to 5 metres) high, as a large reflector, and hence must be kept a white colour. The arc itself can be either entirely obscured by means of a metal reflector (Fig. 63), or partly obscured by a translucent glass reflector (Fig. 64), according to the requirements. In the latter case some light passes directly through, coming principally from the upper negative carbon. In spinning mills (or where easily inflammable material is likely to drop into the bottom reflector) the arc must be entirely enclosed, owing to the danger arising from dust-laden, explosive air. This may be accomplished by means of a glass cover, which fits over the metal reflector, as shown in Fig. 65. In rooms of greater height than 16 feet, or in rooms in which the ceiling is not suitable as a reflector, a special white enamelled reflector, 30 to 35 inches (800 to 900 mm.) diameter, is fixed over the arc.

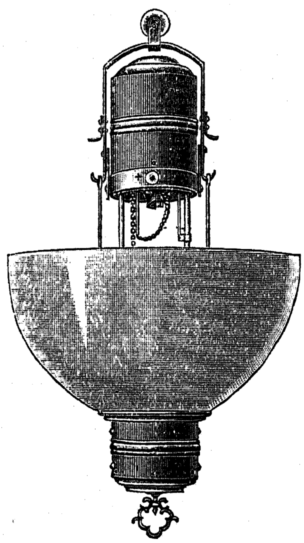


FIG. 64.

The arrangement of the positive carbon as the lower carbon has, however, the disadvantage that particles dropping from the upper carbon fall in the crater, and disturb the arc more or less until they are burnt up. For this reason it is desirable to choose the carbons as thin as possible, having regard to the period of time for which they are required, and only to use carbons of good quality. Lamps constructed with this arrangement of the carbons, and having an open arc (and also

those with a clear glass cover), throw on to the ceiling a strong shadow of the upper portion of the lamp, which is often undesirable. This disadvantage disappears with a normal arrangement of the positive carbon as the upper carbon, and with a reflection of the rays from the crater to the ceiling. Here, too, according to particular requirements, either opaque, enamelled reflectors (Fig. 63), or translucent reflectors (Fig. 64), which allow some of the light to pass downwards, but throw the major portion upwards, may be chosen. In consequence of the double reflection (*i.e.* a reflector and ceiling), the loss of light in this arrangement is comparatively large. Hence the illumination, in comparison with the arrangement with the positive carbon as the lower carbon, is only obtained with a greater expenditure of energy. But still, where it is applicable, this is the best in quality for artificial lighting of interiors in which work of any kind is conducted. A special device for obtaining light indirectly with an ordinary direct current arc lamp is the Siemens-Schuckert reflector (Fig. 66). It consists of a large, bell-shaped, translucent, linen reflector,

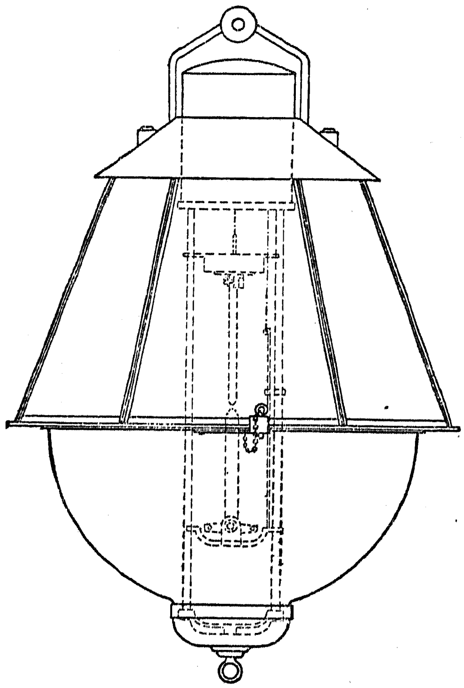


FIG. 65.

A, a small hemispherical alabaster bowl, C, and a clear glass ring, B, of prismatic section. The large reflector is situated above the lamp, and receives up to an angle of 25° below the horizon the upper portion of the rays emitted from the arc. These rays it diffuses and reflects downwards. The alabaster globe encloses the lower portion of the lamp and permits some rays to pass through, whilst casting others up to the reflector A. The intensest portion of the rays, which is emitted from the arc within an angle of 25° to 45°, must pass through the prismatic glass ring placed slightly below the arc, and is thus

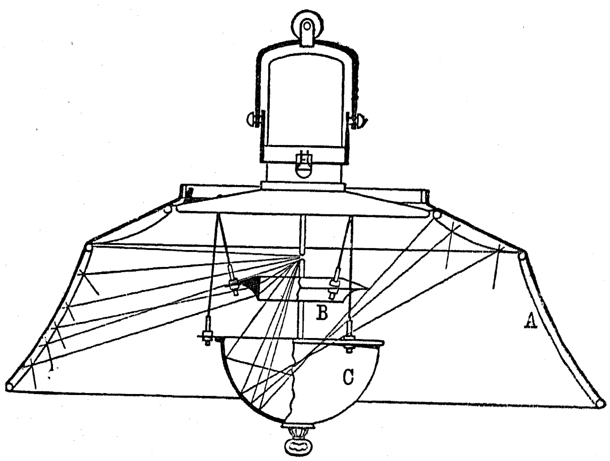


Fig. 66.

so refracted that it also strikes the reflector. In consequence of the transparency of the large reflector, a portion of the light passes through it, and thus a soft illumination of the ceiling and the upper walls is obtained.

Alternating-current lamps may also be used for indirect lighting, though with the same expenditure of energy the illumination is considerably less than with direct-current lamps, and the humming noise of the arc is frequently objectionable.

SIZES OF CARBONS AND LAMP PRESSURES FOR DIRECT-CURRENT ARC LAMPS FOR INDIRECT LIGHTING WITH A POSITIVE LOWER CARBON.

TABLE IV.

Current	6	8	9–10	12	Amperes
Lamp pressure, about ...	41	42	42	43	Volts
Cored carbon	10	11	12	13	Diameter in mm.
Solid carbon	10	11	12	13	Diameter in mm.

Length of cored carbon, 10 inches (250 mm.); length of solid carbon, 6 inches (150 mm.). Period of burning, 7 to 8 hours.

TABLE V.

Current	6	8	10	12	15	Ampères
Lamp pressure, about	40	41	41	42	43	Volts
Cored carbon ...	14	16	17	18	20	Diameter in mm.
Solid carbon	8	9	10	10	12	Diameter in mm.

Length per carbon, 8 inches (200 mm.). Period of burning, about 10 hours. A softer light is obtained with the sizes given in Table IV. than with those given in Table V. The sizes given in Tables I. to III. apply to all other lamps for indirect lighting.

II. FLAME ARC LAMPS.

A. GENERAL REMARKS.

The Flame Arc Lamp, ever since The British Westinghouse Company introduced it into Great Britain, has rapidly gained in popularity. Its warm, attractive glow has caused it to be much sought after for shop lighting, places of entertainment, etc. On account of the brilliant appearance of the lamp, a greater efficiency than the ordinary open type arc, and an excellent light distribution, it is being widely applied to lighting of large spaces, such as railway stations, engineering yards, parks, etc. The so-called "Sun-ray," or golden flame arc, has a fog-penetrating power, and thus renders it of special value for docks and harbours. The flame arc lamp is also being made available for interior illumination.

B. FLAME ARC LAMPS WITH CO-AXIAL CARBONS.

The flame arc lamp is simply an ordinary open type of arc lamp,* but with certain modifications, and can be arranged to burn with direct or alternating current. Briefly, the modifications are—

(a) Chemical carbons mineralized with certain metallic salts (or electrodes with a refractory conducting material other than carbon, see p. 13).

(b) Suitable alteration in the striking mechanism, owing to working with a greater length of the flame arc than in the ordinary open type. The length of flame arc for a P.D. of 40 volts is about 15 to 16 mm., whilst the average length of arc in the ordinary open type for the same P.D. would be about 2 mm.

(c) An economizer, consisting usually of an inverted fireclay bowl, fitted above the arc (Fig. 67).

In order to obtain a light sufficiently steady for the requirements of exterior lighting, as little as possible of the carbon tip should be exposed to the arc, therefore carbons as thin as possible are employed. In the direct-current lamp the uppermost or positive carbon is made the same size as the negative. But since, under ordinary circumstances, the positive carbon burns away twice as quickly as the negative, it is necessary, if a fixed burning position is to be retained, to supply a hollow space, as in that of the economizer, in which an atmosphere deficient in oxygen can collect around the upper carbon. The combustion of the latter is thereby retarded, and the automatic equalization of the combustion of the two carbons is thus effected.

In certain flame arc lamps the lower carbon is made positive. In that case it must be proportionately thicker than the negative carbon. The light is then more steady and the colour more uniform than in the former case—presumably because the added

* A practical enclosed flame arc lamp has been patented by M. André Blondel, Paris. British patent No. 4677 (1906).

chemical substances offer a steadier resistance, and because the thicker lower carbon protects the flame against the ascending currents of air. In spite of the absorption of light due to reflection of light at the surface of the economizer, there is not

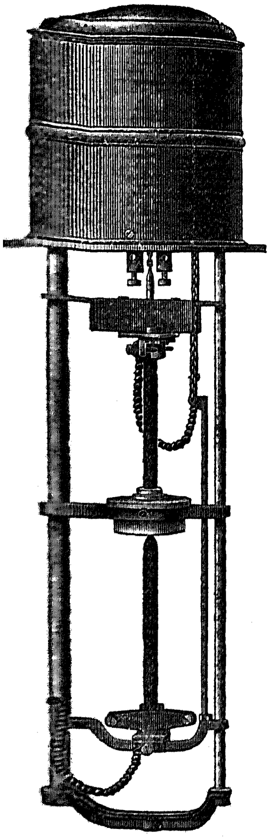


FIG. 67.

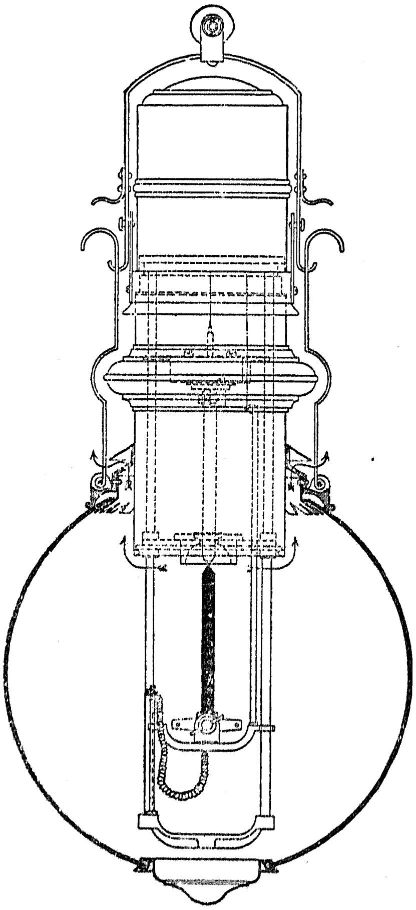


FIG. 68.

much loss of light with this arrangement, because the thicker carbon delivers more of the added chemicals to the flame.

It is necessary to isolate as far as possible the portion in which

the flame burns, in order that the injurious gases produced by the chemically prepared carbons should not reach the lamp mechanism, but pass freely into the outer air. This is generally effected, as shown in Fig. 68, by a metal cover fitting in a groove in the lamp casing and fixed to the lamp frame and also gripping the economizer. Suitable vent holes are pierced in the outer portion of the lamp, and these are provided with a cover, in order to keep out rain.

With alternating current the special arrangement of an economizer may be omitted, since the consumption of both carbons is the same. Instead of the economizer a reflector is generally introduced. Motor lamps also do not require a modification of the striking effort.

Sizes of Carbons and Lamp Pressures for Flame Arc Lamps with Co-axial Carbons.

TABLE VI.

DIRECT CURRENT (UPPER CARBON POSITIVE).

Current	6	8	10	12	15	Amperes
Lamp pressure, about	39	40	40	41	42	Volts
Chemical carbons, upper and lower ...	8	10	11	12	14	Diameter in mm.
Period of burning—						
Length of each carbon 10 ins. (250 mm.)	7	7½	8	8	10½	Hours
" " 12¾ ins. (325 mm.)	9½	10	11	11	14	"

TABLE VII.

DIRECT CURRENT (LOWER CARBON POSITIVE).

Current	6	8	10	12	15	Amperes
Lamp pressure, about	39	40	40	41	42	Volts
Chemical carbon, upper	7	8	9	9	10	Diameter in mm.
" " lower	9	11	12	13	15	
Period of burning with economizer—						
Length of each carbon 10 ins. (250 mm.)	7	7½	8	8	10½	Hours
" " 12¾ ins. (325 mm.)	9½	10	11	11	14	"

TABLE VIII.

ALTERNATING CURRENT.

Current	8	10	12	15	20	Amperes
Lamp pressure, about ...	30	30	30	30–34	30–34	Volts
Chemical carbons, upper and lower	8–10	9–11	10–12	12–14	14–16	Diameter in mm.
Period of burning—						
Length of each carbon 8 ins. (200 mm.)	6–7	6–7	7–8	7–8	7–8	Hours
Length of each carbon 12¾ ins. (325 mm.)	10–12	10–12	11–13	11–13	12–14	„

The thicker carbons in Table VIII. and their corresponding longer period of burning are for yellow or "Sun-ray" light, and the thinner (chemical) carbons with corresponding shorter periods are for a white or "White-ray" light.

C. FLAME ARC LAMPS WITH INCLINED CARBONS.

The ordinary arrangement of co-axial vertical carbons has given place to inclined carbons with their tips pointing downwards, as shown in Fig. 6, the latter arrangement being much more suitable for chemical carbons. There is a tendency for the chemicals, appearing as a fine ash, to gather on the outside of the co-axial carbons or to form a slag, with a consequent reduction of the light. Since the larger portion of the light comes from the arc, it should be allowed to pass downwards without shadows. The carbons are mounted side by side above the globe, meeting generally at an angle of about 15°, and the arc formed between the tips is repelled in a bowed form, either by the magnetic field produced by the loop circuit consisting of the "+ carbon, arc, and − carbon," or by the special employment of

so-called blow-down magnets* (Figs. 70A–70C) through which the current taken by the lamp passes; the action of the blow-down magnet upon the arc being the well-known repellant effect that the magnetic lines exert on the flexible current-carrying arc. The deflection, and hence the formation of the arc, is then readily controlled by this blow-down device, and the magnetic field may be strengthened or weakened according to desire. The stronger the field the more the flame expands. With currents of from 8 to 15 amps., and an angle of 15 to 20 degrees, a special blow-down magnet is usually unnecessary; but with a small current an increase of its own field, and with a current above 15 amps. a weakening of its own created field by means of a blow-down magnet, are of advantage.

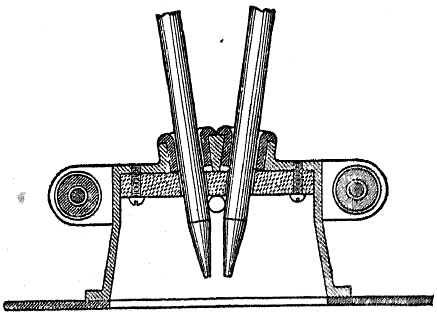


FIG. 70A.

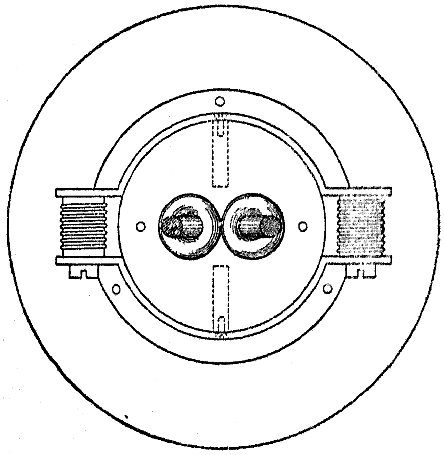


FIG. 70B.

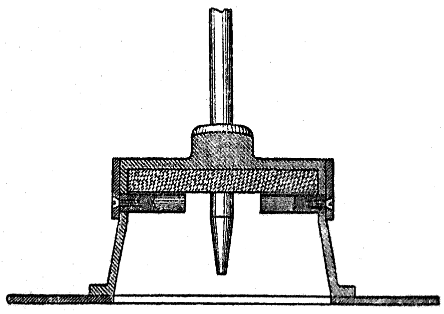
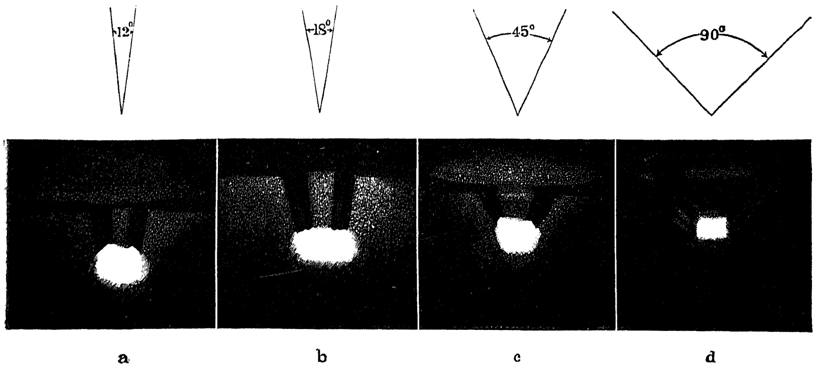


FIG. 70C.

* See also p. 91, Fig. 86.

PLATE IV.

Direct Current, 45 volts, 10 amperes.
Without the blow-down magnet.



Alternating Current, 45 volts, 10 amperes.

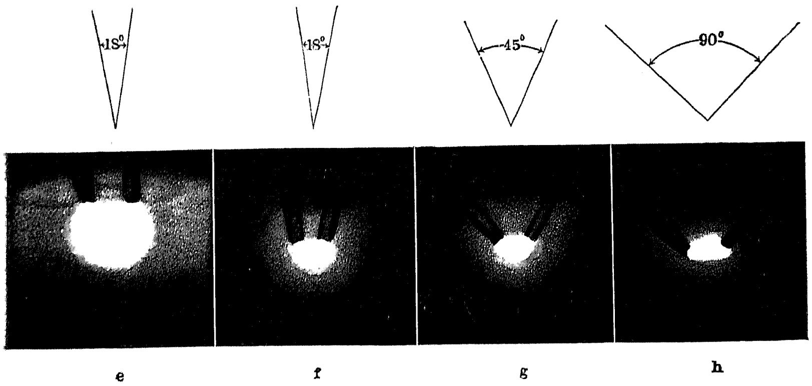


FIG. 69.

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In Fig. 69 (Plate IV.) the illustrations *a* to *d* (for direct current) and *e* to *h* (for alternating current) show how the flame forms with different inclinations of the carbons up to an angle of 90°. The illustrations *e* and *f* are for the same

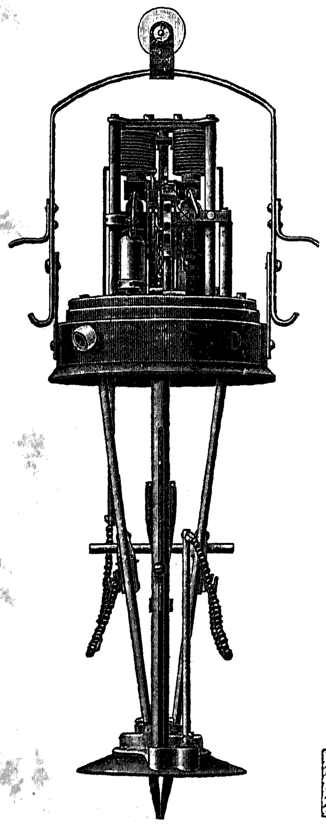

Fig. 72.

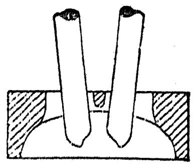

Fig. 71.

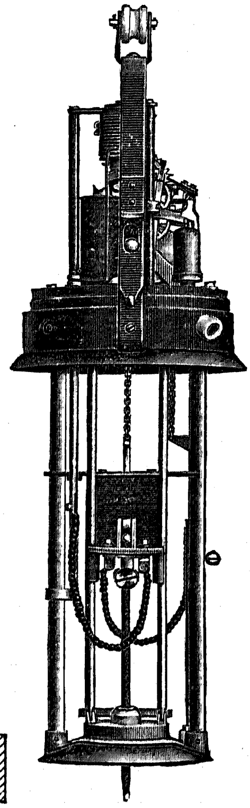

Fig. 73.

angle, but in *e* the current was made somewhat larger. The shape of the flame in illustrations *a*, *e*, and *f* resembles that of a soap bubble covering the bowl of a tobacco pipe.

The carbons pass through holes in a bowl-shaped economizer whose function, it has already been remarked, is to keep the

hot carbon tips in an atmosphere deficient in oxygen, thereby reducing the consumption of the carbons and thus saving in both cost of carbons and trimming. The economizer also serves as an excellent reflector, as it is covered with the white ash deposit and protects the flame from draughts. To get the best results, the carbon tips should not project below the level of the rim of the economizer. Fig. 71 shows the cross-section of an economizer in an "Excello" arc lamp (Union Electric Co.), and exhibits at the same time the correct position of the carbons. The position of the carbons is dependent on the length of the arc, and this is naturally controlled both by the voltage available for the arc and the quality of chemical carbon used. In this lamp great stress is laid upon the correct elevation of the arc in the economizer. If, after it has burnt long enough to be properly formed, the carbon tips remain too high inside the economizer, it is evident that the voltage of the arc is too high, indicating at the same time that the current is too great. To remedy this, it is only necessary to increase the steadying or line resistance; and conversely, to diminish the resistance when the carbon tips are below the level of the economizer.

On the whole, the regulating mechanism is usually the same as in the direct and alternating current lamps already described. The only difference lies in the fixing of the carbon holders. These must be so arranged that both carbons may be fed downwards at the same time, and to the same extent, as they burn away. There is also a different method of separating the carbon tips in the act of striking.

The regulating mechanism in Figs. 72 to 80 is differential, the magnet system in the A.E.G. flame lamp (Figs. 72 to 74) being the same as in the ordinary type described on p. 57. The electro-magnets in the Union "Excello" flame lamp (Figs. 75, Plate V., and 76) are at right angles to one another, *h* being the series magnet, and *n* the shunt magnet. Both lamps are of the clockwork type, but whereas the swinging frame in the

PLATE V.

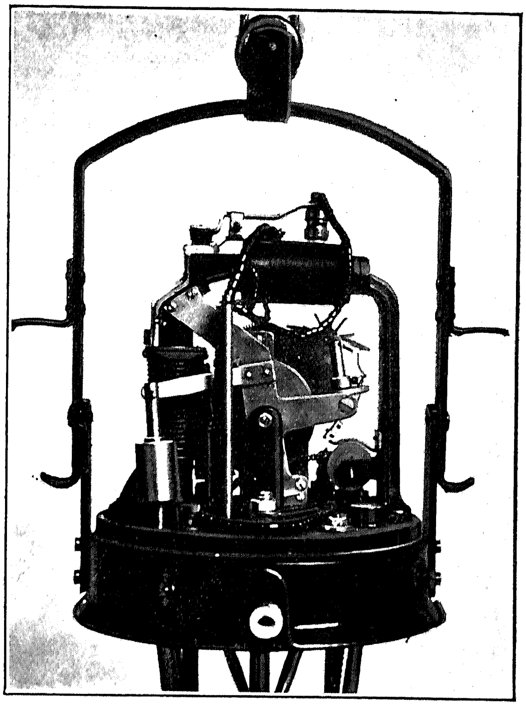

FIG. 75.

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A.E.G. lamp carries the 'scape wheel, in the "Excello" lamp it is the detent which is fixed to the swinging frame. In both lamps the feed is regulated by the detent (H in Fig. 74, and *f* in Fig. 76). In the A.E.G. lamps (Figs. 72 to 74 for direct current, 77 to 79 for alternating current), the feed is obtained as follows: the two carbon holders are suspended from a cross-piece, *T* (Fig. 74), to which are attached guide-pieces which, in ordinary lamps, the upper carbon possesses. Besides the guide-frame tubes for these, there are arranged at right angles two pairs of inclined guide rods for the carbon holders. As the carbon holders slide down, when free to move, they also move inwards on the cross-piece *T*. A fireproof reflector is attached to the lower ends of the frame tubes.

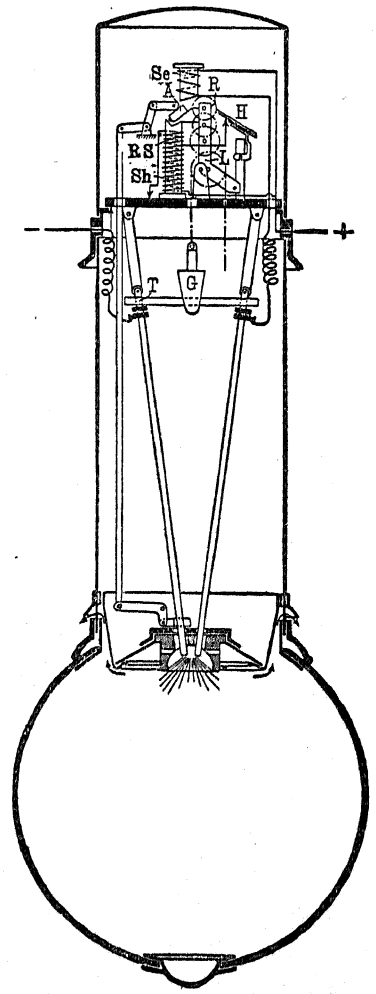

FIG. 74.

Another practical construction to obtain an equal feed is that in which both holders slide on inclined guide rods and are suspended by copper cords or chains, which pass over a common cord or chain-pulley (Fig. 81). The "Excello" lamp possesses such a feed (see Fig. 76).

The feed in all the flame arc lamps described, except in the alternating-current motor lamps, is operated by the weight of the carbon holders. In order to insert new carbons in lamps of the type shown in Fig. 72, an upward movement of the

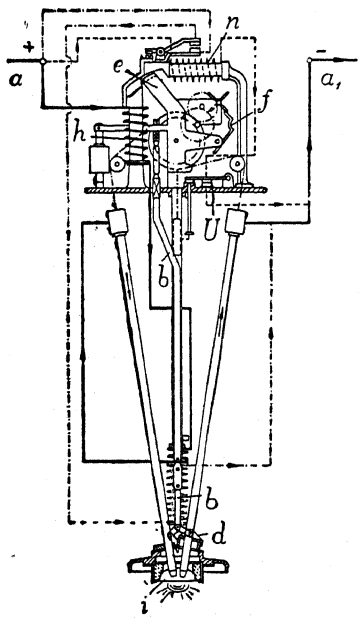

FIG. 76.

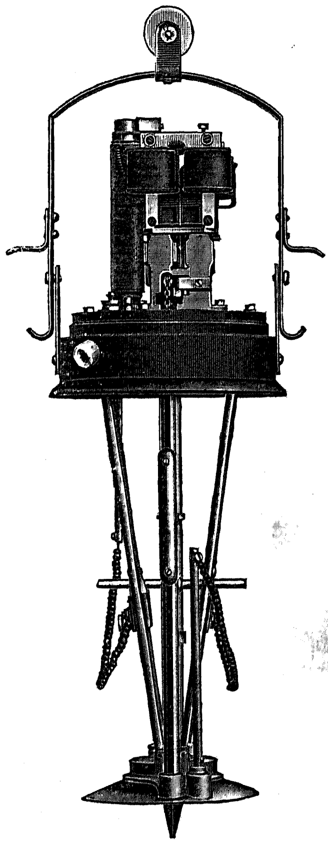

FIG. 77.

holders is effected by a pull on the loose end of the chain, whilst in lamps with a cord or chain-pulley, a third cord or chain for use by hand is usually inserted (Fig. 81).

The shunt magnet brings the carbons together, and the series

magnet separates them and checks the feed. For striking the arc and separating the carbons a few millimetres they would need

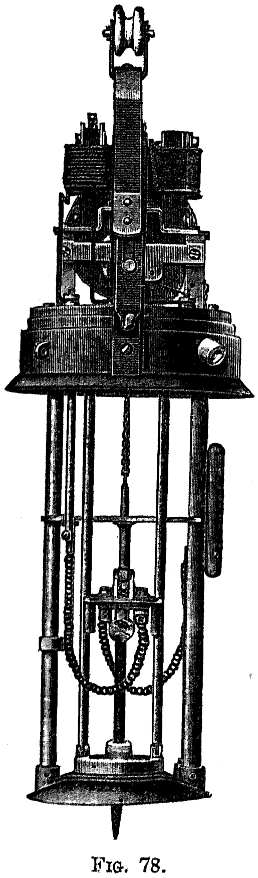

FIG. 78.

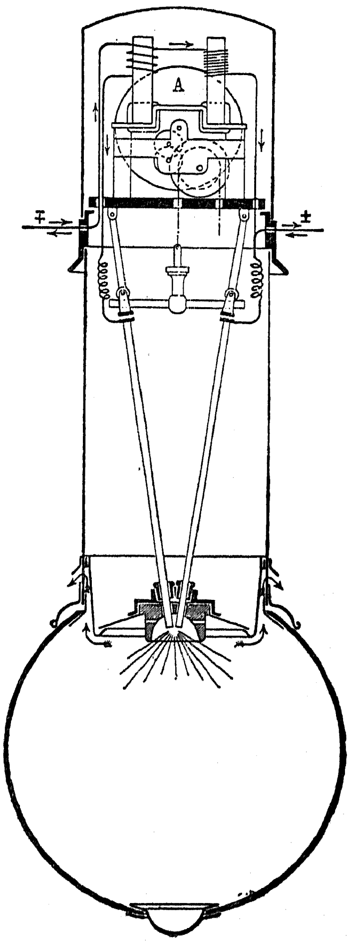

FIG. 79.

to be raised up considerably after contact of the tips, owing to the small acute angle at which they are placed. This is generally only possible with motor lamps (Figs. 77 to 80) which are not

limited to any fixed striking effort or pull. Lamps with a definite striking pull, *i.e.* all direct-current lamps, must therefore be provided with a system of levers which, when the current passes through the series coil, participates in the movement of the armature, and so causes a separation of the carbons. This movement either the whole carbon holder or only the carbon itself may share. In Fig. 74 the connecting rod and crank lever controlling the negative carbon is attached to the armature A. In Fig. 76 the slider *d* is connected to the rod *b*, which in turn is fixed to the swinging frame *e* in such a manner that the movement of the armature towards the series magnet causes a side movement of the extremity of the carbon rod.

In all these flame arc lamps the carbons must, in the interests of a steady light, be chosen comparatively thinner than in the lamps described before. Consequently, if they are to burn for the usual time (6 to 18 hours), the carbons must be considerably longer, and thus their ohmic resistance, which cannot be neglected, is introduced. For this reason, in lamps burning more than 6 hours it is not sufficient to conduct the current to the carbon holders, but special clutch contacts, as in Figs. 81, 81A, and 81B, must be introduced in the neighbourhood of the carbon points (see also Fig. 90). It has also been mentioned * that chemical carbons are used with their conductivity increased by means of a copper deposit or a zinc gauze covering or core, etc., so that in this case the special contacts may be omitted.

In order to prevent the economizer, as well as some of the metalwork, from possible destruction by the arc travelling up when the carbons have burned away as far as permissible, *e.g.* when the holders have reached the lowest possible point, there are introduced into these lamps special contrivances for extinguishing the arc in such cases. These contrivances may

* Chapter I., p. 13.

consist of either a cut-out for the shunt coil, or in the switching in of a blow-out magnet. The cut-out may be operated by a carbon holder. In Fig. 76, for circuits up to 125 volts, the shunt circuit is automatically broken by the carbon-faced switch *U*, mechanically operated by a small detent on the chain connecting the carbon holders, and causing the series-wound magnet

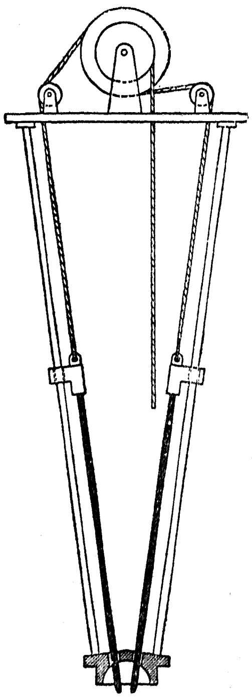

Fig. 80.

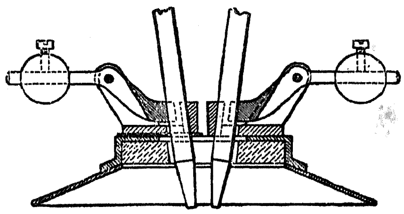

Fig. 81A.

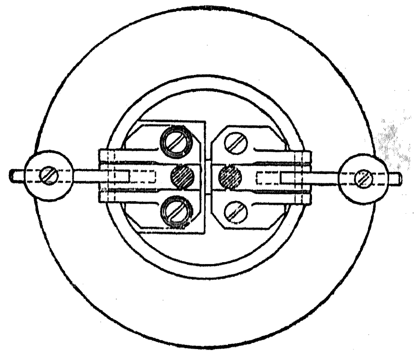

Fig. 81B.

to draw the armature right over and separating the carbons as far as possible, thus extinguishing the lamp. In the A.C. lamp in Fig. 82 the shunt circuit is similarly broken by the cut-out *U*; the series magnet then winds the carbons apart until the arc breaks. For the higher voltages, say 240 volts, the above cut-out is not sufficient to extinguish the arc for the D.C·

lamps, and therefore the blow-down magnet, which is excited by a series winding whilst the lamp burns, has an extra shunt winding on it (the blow-down magnet) inserted at the moment of switching out the shunt magnet coil; thus strengthening the magnetization and extinguishing the arc.

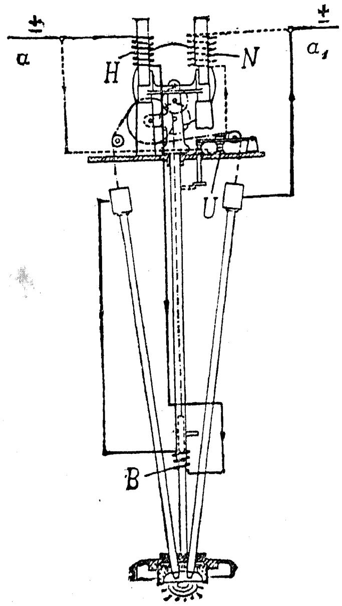

FIG. 82.

The guide rods can also be bent in such a way that an increased separation of the carbons occurs when the carbon holders reach the lowest position. All these devices have the same object, viz. to extinguish the arc by a sudden separation of the carbons, and the simplest device of all is to insert carbons which are *not cored* at the end inserted into the holder. Then as the carbons burn down to the uncored portion, the conductivity is suddenly reduced; thus the current is not so readily conducted, and the arc is extinguished as a direct consequence.

The case must be constructed so that the globe space which contains the light shall be entirely shut off from the upper portion of the lamp, in order to exclude the injurious nitrous oxide fumes which are generated, and the necessary *vent holes must offer a free outlet* for these gases. This is usually effected by a special protecting cover (Figs. 74 and 79) at the lower end of the lamp frame, to which is fastened a plate fitting the case as closely as possible. Owing to the presence of these nitrous fumes, it is desirable that in all flame arc lamps with inclined and co-axial carbons all iron and steel parts should be

PLATE VI.

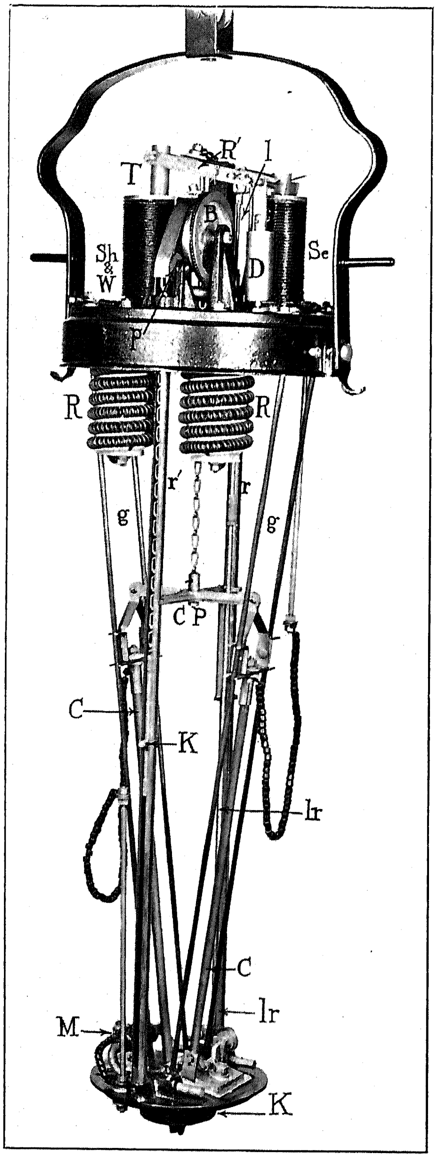

FIG. 83. [*Between pages* 88 *and* 89.

PLATE VII.

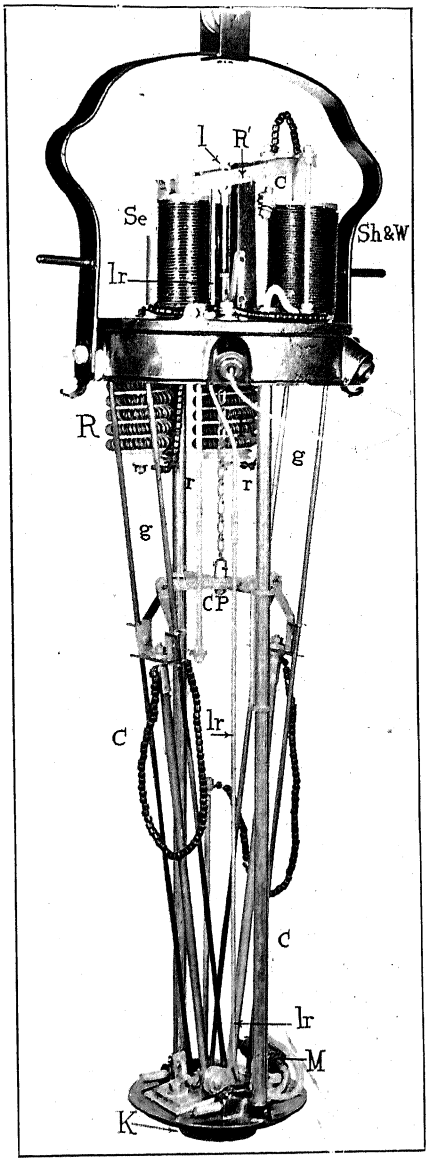

FIG. 84.

[*Between pages* 88 *and* 89.

enamelled or lacquered with a heat-resisting and rust-preventing enamel. It is also better to avoid the use of steel in delicate parts.

The British Westinghouse Flame Arc Lamp.—The flame arc lamp which the British Westinghouse Co. first introduced into this country was the Bremer lamp—the pioneer of magazine lamps—but it was rather too complicated for ordinary use. The flame lamp the Company now supply is very simple and of substantial construction. The lamp is a good example of the distinctively British type of brake-wheel feeding mechanism with the see-saw striking lever (see p. 60). For this reason we propose to give a detailed description of their lamp for direct current.

The magnetic system is differential, consisting of a series solenoid, Se (which strikes the arc and arrests the feed in the usual manner), and a shunt solenoid, Sh, whose function on switching the lamp is to bring the carbons together before the arc is struck and to feed the carbons after it is struck (Figs. 83 and 84, Plates VI. and VII.). The cores of the solenoids are suspended from the opposite sides of a rocker, R′, the movement of which is steadied by the dashpot D.

The carbons C, C are fixed in holders which slide on the pairs of inclined guide-rods *g*, *g*, and which are hung from the two opposite ends of a centre cross-piece, CP, which slides on the tubes *r*, *r′*. The cross-piece is attached to the end of a chain which passes over a chain pulley, T, the guide pulley *p*, and through the slotted tube *r′*, terminating in a short rod with a knob, K, projecting through the slot. Thus in adjusting or re-carboning the lamp the holders may be raised by pulling K down. T is attached to the side of the brake-wheel B, round which the brake chain *bc* passes (see Fig. 85). One end of *bc* is fixed at *f*, and the other is attached to a lever pivoted at X; the helical spring S tends to keep L down and *bc* taut round B, so that B and T are prevented from rotating. When, however, the shunt solenoid (Fig. 84) pulls its core down,

the link rod *l* (and with it the lever L) is raised by the tilting of the rocker (whose position when the lamp is out of circuit is as indicated), so that the brake is taken off B; the cross-piece hence falls by its own weight, and the carbons are fed forward. It should be noted that the upper end of *l* has a long slot in it, and is therefore unaffected by the movement of R′ when the

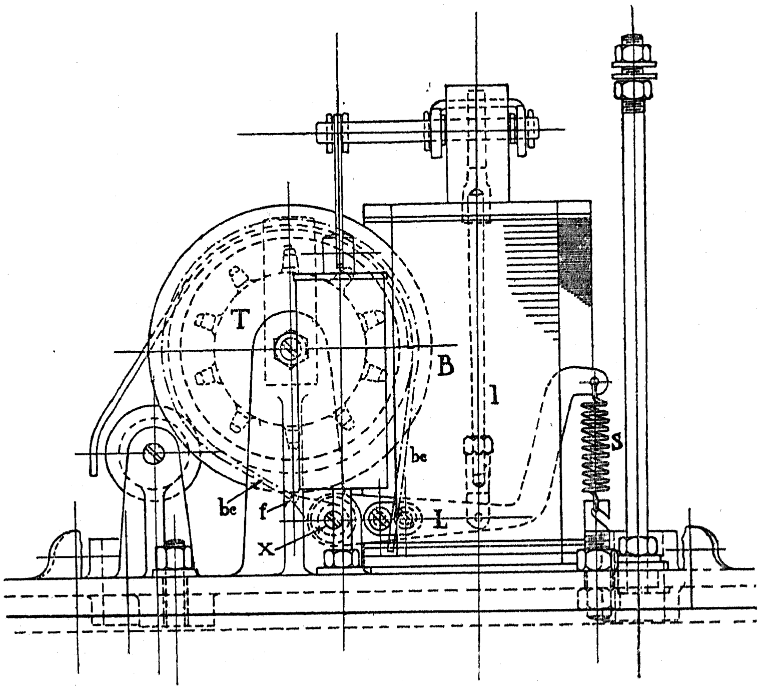

Fig. 85.

latter is tilted in the reverse direction by the series solenoid. As soon as the current passes through the series coil (when the carbons come in contact), its core moves down, and the long rod *lr*, which passes right down to the foot of the lamp, participates in this movement and actuates the striking mechanism. This is more clearly illustrated in Fig. 86 (Plate VIII.), where the

PLATE VIII.

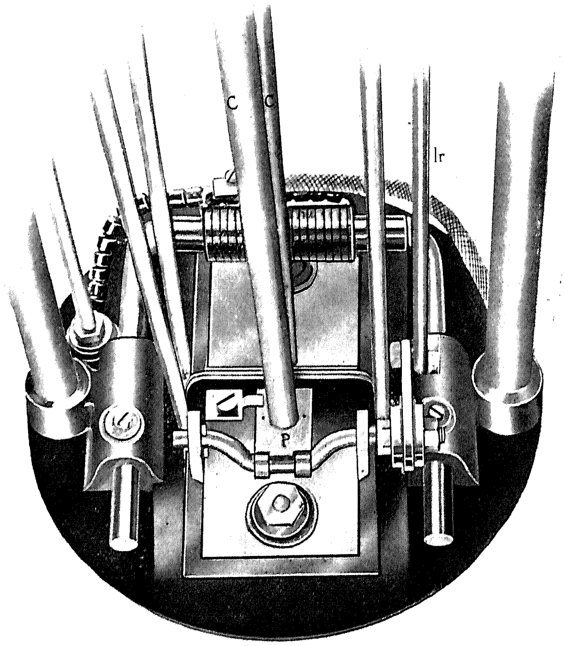

FIG. 86.

[To face page 90.

carbons C, C pass through close-fitting holes in mica-insulated plates on the cast-iron foot F, to which the cast-iron economizer is fixed. One of the plates can move sideways, and is connected to the long rod *lr* through the small crank and the lever. Thus when *lr* is lowered by the energizing of the series coil, the side movement of one carbon occurs and the arc is struck. Conversely, the shunt coil would cause *lr* to be raised, and the tip of this carbon to be brought nearer to the other one. Hence this striking mechanism virtually does part of the feeding, for as the carbons burn away, with a resulting lengthening of the arc, Sh raises *lr*, and the plate moves inwards. This action takes place for some time before the brake-wheel is released and the carbons feed downwards.

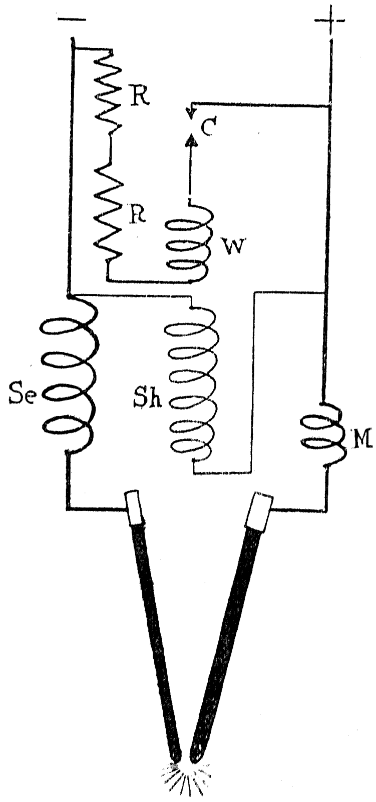

Fig. 87.

The flame arc is of a colour depending upon the carbons employed, and is deflected downwards by a blow-down magnet, M, excited by a winding connected in the main lamp circuit, as will be seen in Fig. 87, showing the diagram of connections and also the substitutional circuit, consisting of an automatic switch, C, and substitutional resistance, RR. This circuit is dispensed with in lamps intended for working singly, but is provided when two, three, or more are connected

on constant-pressure circuits. We shall have occasion to refer to this compensating circuit on p. 172.

The Magazine Flame Arc Lamp.—The magazine lamp has been designed to burn longer with flame carbons and to save trimming. It has the further advantage that the carbons may be burnt to a stump.

In the "Oriflamme" arc lamp made by the Oliver Arc Lamp Co., we have a magazine lamp containing in its storage chambers or magazine nine pairs of carbons of small diameter (7 mm. and 6·35 mm. for the 9-ampere size), and will burn from 36 to 40 hours. It is claimed that by using flame carbons of cheap quality and of small diameter a saving in carbons is effected and a steadier burning obtained. As the lamp works on new lines, and scarcely falls into the classifications we have made, it is desirable to explain at some length the details of its construction and working.

In Fig. 88 the two downwardly extending limbs of the framework, terminating at a point just above the arc, form the poles of the blow-down magnet, excited by winding *a*, which is placed horizontally and connected in the main circuit. The framework forms the positive pole of the lamp.

The carbon magazines (Fig. 89) consist of flat receptacles, in which the carbons are contained one behind the other. Provision is made at the back of the magazines for inserting the carbons. Spring arms, *b*, bear upon the carbons and keep them pressed up to the discharging side of the magazines. Close up to the inner edge of the magazines and closing it, is an endless chain rotating over sprocket wheels. Two projections, *c*, on each chain, the length of a carbon apart, project in turn into the magazine and engage with the foremost carbon, feeding it forward from the magazine through the carbon holder. As each pair of carbons is fed forward, others are pressed into position by the spring arms, to be pushed forward in turn by the projections on the chain. The top sprocket wheels of each magazine are

mounted on the same shaft, *d* (Fig. 90), which is revolved by means of a pawl engaging with a ratchet wheel, *e*, mounted upon the shaft. As each carbon issues from the lower end of the magazine it passes through a weighted clutch, *f*, which serves to convey the current to the carbon as well as to retain it in position (see also p. 87).

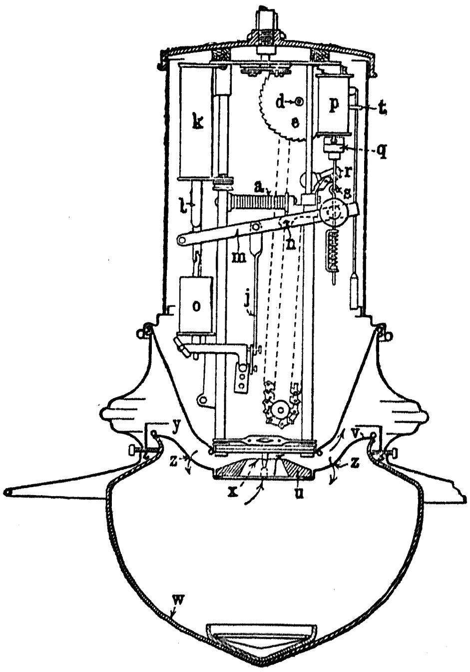

FIG. 88.

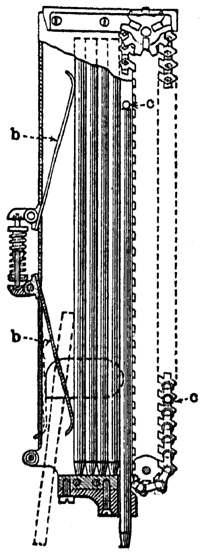

FIG. 89.

In order to strike the arc after the carbons touch and the current passes between them, one magazine, the negative, *g*, being loosely pivoted at *h* at its upper end in a bracket fixed on and insulated from the framing, is caused to swing away from the other one, the positive, which is rigidly fixed and is uninsulated from the framework of the lamp. The movable magazine

is connected by means of a bell crank lever and link *j* to the regulating mechanism whence it derives its movement.

The regulating mechanism consists of a pair of solenoids, *k*, mounted side by side in the framework, and having a horseshoe iron plunger working within them. Each solenoid is differentially wound, *i.e.* consists of a series and a shunt winding in opposition. The movable plunger is pivoted on a "knife-edge" bearing a rocking cradle, *m*, which in turn is also pivoted on "knife-edges," *n*, to the framework. The link *g* is pivoted on this cradle, so that the tilting of *m* imparts a movement to the point of the carbon projecting below the swinging magazine.

Before the lamp is switched on, the two carbons are separated and the plunger *l* is in the lowest position. Switching in causes the shunt winding of *k* to tilt the rocker so that the carbons come into contact. Simultaneously the drop of voltage causes the solenoid to be weakened, and the movable plunger drops, and therefore a striking of the arc ensues; a dashpot, *o*, damps any violent movement. The pull of the regulating solenoids against the action of gravity, depending upon the voltage across the arc, maintains an equilibrium and keeps the arc at its correct burning P.D. The reverse end of the rocking cradle is weighted to obtain a balance corresponding to the voltage of the arc it is desired to maintain. The side movement of the magazine feeds the carbon until no further movement is available. It is then that a magnetic feeding motor feeds the carbons from the magazines by rotating the ratchet wheel and shaft connected with the chains of the two magazines. The motor consists of a horseshoe electro-magnet, *p*, provided with a loosely pivoted iron armature, *q*, and excited by a small shunt current. In its circuit is the make-and-break switch *r*, which is normally in the "off" position. The switch is provided with links, *s*, both connecting with the regulating cradle and with the armature. The cradle, by its movement, closes the switch, and the armature, when it lifts, opens

it and allows the armature to fall again. The armature, provided with pawls, *l*, engaging with the rachet wheel, as above mentioned, by its reciprocating action causes rotation, and consequently a feed of the carbons from the magazines, until the proper relations of current and voltage are restored. The

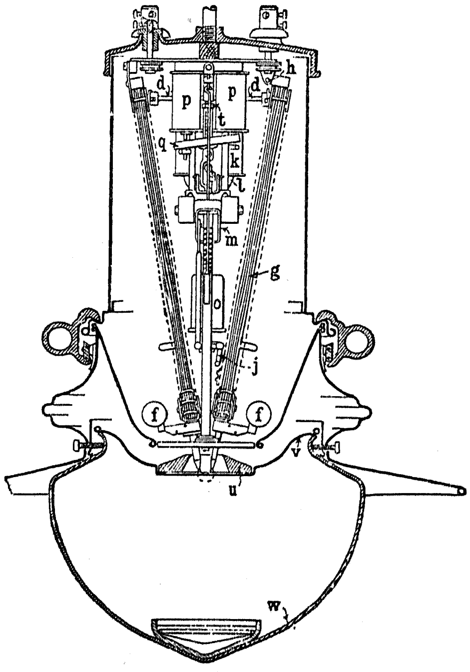

FIG. 90.

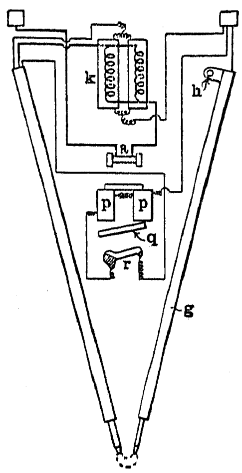

FIG. 91.

switch is an exhausted glass tube containing mercury and two platinum leading-in wires, one end of the tube being enlarged (Fig. 91). To prevent a possible breakdown of the insulation on the winding of *p* on breaking this circuit, a spark gap is placed across the winding as a protection.

The porcelain reflector *u* is provided with a plate, *v*, which closely engages with the top and only opening of the globe *w*,

and is also air-tight. The heated gases pass through the central passage *x*, which connects the globe with the space *y* above *v*, the ventilation being facilitated by a small supply of air entering the globe through holes, *z*, in the reflection plate. A glass and copper gauze tray at the bottom of the globe catches the short ends of carbons as they are discharged from the magazines.

The lamp works with a substitutional resistance and an automatic cut-out (see p. 172), which take the place of the lamp when the stump of the first carbon falls through, and also for series working of lamps, so as to keep the remainder burning. During interruption of the series current in the lamp, the shunt winding of *k* swings the magazine inwards and starts the ratchet magnet *p*, until in about 20 to 30 seconds the arc strikes on the new carbons fed through the holders, the automatic switch opening to allow the arc to strike when the carbons come together.

The alternating current magazine lamp by the same firm has laminated cores and a choking coil instead of an adjustable line resistance used in the direct-current lamp, otherwise the movement is exactly like the latter.

All flame arc lamps with inclined carbons are generally regulated, both with direct and alternating currents, for a P.D. across the arc of about 45 volts. Hence, with 110 to 120 volts two lamps, and with 220 volts four lamps, can be connected in series; that is, about 55 to 60 volts of the supply pressure per lamp are required.

Both kinds of flame arc lamps may, of course, burn in series with ordinary lamps, in so far as they regulate with them, but the light of the latter will be more influenced by the less steady flame arc, so that such series working is not always suitable.

Sizes of Carbons and Lamp Pressures for Flame Arc Lamps with Inclined Carbons.

TABLE IX.

DIRECT CURRENT.

Current	8	10	12	Amperes
Lamp pressures, about	45	45	45	Volts
Positive chemical carbon	8	9	10	Diameter in mm.
Negative chemical carbon	7	8	9	Diameter in mm.
Period of burning, about—				
Length of each carbon 12¾ ins. (325 mm.)	6½	7	7	Hours
,, ,, 20 ins. (500 mm.)	11	11–12	12	,,
,, ,, 25½ ins. (650 mm.)	15	16	16	,,

TABLE X.

ALTERNATING CURRENT.

Current	8	10	12	15	Amperes
Lamp pressures, about	45	45	45	45	Volts
Chemical carbons (both of equal diameter)	7	8	9	10	Diameter in mm.
Period of burning, about—					
Length of each carbon 12 ins. (300 mm.)	6	6–7	7	7	Hours
,, ,, 20 ins. (500 mm.)	11–12	12	12	12	,,
,, ,, 23½ ins. (600 mm.)	15	15–16	16	16	,,

With chemical carbons giving a yellowy light, a thin, drossy insulating layer forms on the carbon tips, owing to the chemical used, especially at rather lower lamp pressures. In most cases it falls away when the lamp is switched on, by the simple contact of the carbons, but occasionally it prevents contact, and, in consequence, prevents the striking of the arc. In this case the insulating layer must be removed by hand. By the use only of one chemical carbon and one untreated carbon (the negative with direct current), this evil is almost

H

entirely removed, though at the expense of the intensity of the light, which is decreased by about 20 per cent. or more.

ENCLOSED ARC LAMPS.

A. GENERAL REMARKS.

In principle, the enclosed arc lamp differs from the open type arc lamp, in the provision of an arc enclosure, which protects the carbon tips from the atmosphere, and thereby renders a longer life of the single pair of carbons possible. The potential difference across the enclosed arc is also considerably higher, being about 80 volts as compared with 45 to 50 volts P.D. of the open type.

To keep out the air, a small, elongated glass globe, called the "inner" or "enclosing" globe, is used, which contains the lower carbon, and is therefore either sealed at the bottom, or rests quite air-tight in a removable holder upon a lower cross-piece of the frame. The upper opening of the enclosing globe is closed by a metal cap (the gas cap, as it is sometimes called), which has only a hole for the insertion of the upper carbon. The oxygen of the enclosed air is quickly consumed by the arc, and within the enclosure we have produced a mixture of gases, consisting of nitrogen, carbon monoxide, and carbon dioxide, etc., in which the consumption of the carbons is retarded. The consequence is that the carbons do not assume a pointed shape, as happens with carbons burning freely in the air, but assume the form shown in Fig. 3. The surface of the positive tip is very slightly concave, and that of the negative very slightly convex, the edges being irregular. But with the currents and size of carbons usually employed, the arc only covers a portion of the surface, moving so that it is always at the place where the carbons are nearest to each other. This movement and the consequent unsteadiness of the light becomes greater the larger the carbons are in proportion to the strength of current. The length of time

during which a single pair of carbons will burn is greater if the burning is continuous; for, if the lamp be switched off, the gases cool, and fresh air is drawn into the enclosing globe; and, having a stronger oxidizing effect, causes the carbons to burn more rapidly when the lamp is switched on again.

In consequence of the flat formation of the carbon tips, enclosed lamps must necessarily burn with a longer arc (and hence a higher P.D. across the arc) than is the case with open type arc lamps, otherwise the distribution of the rays would not be good, and a large amount of light from one carbon would be stopped by the opposite carbon. They are therefore regulated with an average P.D. across the arc of 75 to 80 volts with direct current, and 65 to 70 volts with alternating current, whilst the volts consumed in the lamp (line) resistance amount to about 40 per cent. of the nominal lamp pressure.

Owing to the length of the arc and the slow combustion of the carbons, enclosed arc lamps do not require an accurate feed like open type lamps, and are made, for the sake of simple and strong construction, of a clutch type. The enclosed arc lamp is adapted to operate on the different commercial systems, such as incandescent lighting, power, and tramway equipments. For the first system the lamps are styled multiple lamps, and operate on 110 and 220 volts direct current, and 110 volts alternating current constant potential circuits, in which case the lamp is best of the series magnet type; whilst in the second class of equipment, lamps operating in series on both alternating and direct constant current circuits—and in the third class of equipment, which is a combination of the first and second classes, the lamps operating in multiple series on constant potential circuit, are made of the differential type. The enclosed arc lamp is not suitable as a shunt magnet type, owing to the movement of the arc and the consequent great change in the *arc* resistance. In such a case the lamp current and the light emitted would vary too much.

On page 19 (Fig. 18), a series magnet type of lamp with a clutch is shown, and the mechanism explained.

Fig. 92 is a differential type (A.E.G.), for currents of about 2 amperes, with a claw-clutch feed. The mechanism is very simple.

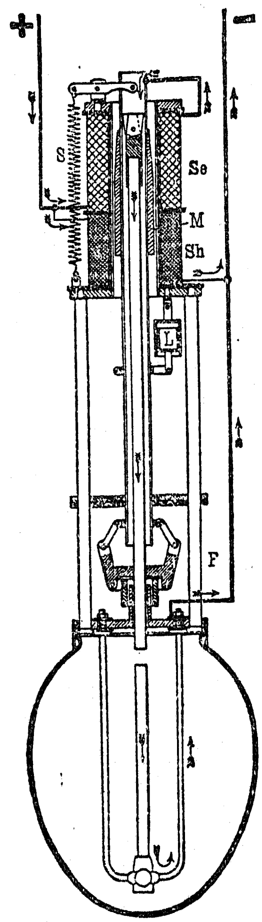

Fig. 92.

Before switching-in the lamp, the core M, together with the support and the clutch F, sink until F rests upon the globe cap, and the claws open. The upper carbon is then free, and falls into contact with the lower carbon. When the lamp is switched in, a strong current passes through the carbons and the series coil Se; the latter pulls up the iron core and the clutch F, which then grips the upper carbon and lifts it away from the lower one, whereby the arc is struck. At the same time a current passes through the shunt coil Sh, whereby a pull in the opposite direction to that of the series coil is exerted upon the iron core, and this pull increases with the P.D. across the arc. As the carbons burn away, the attraction of the shunt coil preponderates, and the iron core and upper carbon are pulled down, so that the attractions of the two coils maintain an equilibrium. If the downward movement extends so far that the clutch rests upon the globe cover, then the claws open and liberate the upper carbon. The electrical conditions in the coils will alter according

as the weight of the carbon and its holder causes them to sink. The shunt coil is weakened in consequence of the decreased P.D. across the arc, and the series coil is more strongly excited, so that the iron core is again pulled up, and the upper carbon again gripped by the clutch, until the play is resumed. The spring S is employed to regulate the lamp according to the desired electrical conditions, the influence of the series coil being re-inforced, more or less, according to the tension of the spring. The spring can, of course, be replaced by a weight. The dashpot L serves to prevent the iron core from responding too quickly to the influence of the coils, and especially to check a too rapid separation of the carbons when the lamp is switched on. Without the dashpot this takes place so quickly that the heat necessary for the striking of the arc is not produced, and the arc cannot be struck.

B. DETAILS OF CONSTRUCTION.

The mechanical construction of enclosed lamps is practically common to all commercial types, so that the following details, we shall consider, apply generally to the entire line :—

1. The electro-magnets.
2. The clutch.
3. The frame for connecting the clutch with the movable core, and for mounting the carbon holders.
4. The carbon holders.
5. The enclosing globe and accessories for fixing it.
6. The dashpot.
7. The adjusting parts (springs and weights).
8. The terminals.
9. The lamp casing and outer globe.
10. The suspension.

1. The *electro-magnets* are usually made in the form of solenoids (Figs. 25, 26, and 27), as a pull of 10 to 15 mm., necessary to form a long arc, is easily obtained with them.

With direct current and 75 volts P.D. across the arc, the carbons are separated by about 8 mm. But in order to allow for the backlash between the clutch and the carbons, etc., the pull of the iron core must be about half as large again.

2. The *clutch* may be constructed in different ways, and, as a matter of fact, more different forms of clutches have been made than of any other part of the lamp mechanism. The ring

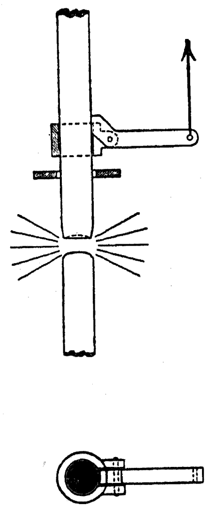

Fig. 93.

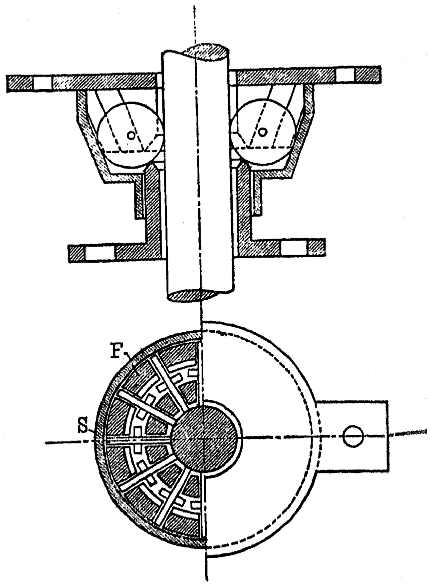

Fig. 94.

clutch in Fig. 18 is a typical construction, as also the ri fitted with a bent lever (Fig. 93). Of other types, the cl clutch (Fig. 92) and the disc or ball clutch (Fig. 94) show t general form. If the clutch be made of metal it should be w insulated, otherwise if the upper carbon is not firmly seated its holder the clutch will attempt to carry current, with t result that the clutch is injured by having its edges fused the point of contact with the carbon. In the Westingho

lamps the clutch is a porcelain ring mounted in a
tal basket or punching, and is thus mechanically
ıd will never carry current.

clutch must prevent the upper carbon from slipping, in
lamp is shaken, and must adapt itself to the unavoid-
ations in the diameter and smoothness of the carbon,
he latter neither sticks nor causes too great a difference
lease of the clutch, which would influence the normal
of the iron core. In this respect the disc clutch (Fig. 94)
satisfactory, whilst the simpler ring, although it holds
n very tight, requires carefully manufactured and very
faced carbons. The release of the disc or ball clutch
s soon as the trough-shaped case has sunk so far that
or balls rest upon the fixed uprights which enter the
the discs can no longer participate in a further down-
vement of the case. Balls have the disadvantage that
r too little friction as the contact surface is so small.
es and balls must be so arranged that they cannot fall
the carbon is removed. Both are therefore protected
tted plate surrounding the carbon, and the discs are
with short axles.

e *frame* connecting the core to the clutch is made of
s or tubes according to the type of construction.

e *carbon holders* may be made from split bronze
r as in Fig. 38; since, as a rule, enclosed arc lamps
n with small currents of about 3 to 6 amps. The
rbon holder is generally held in a metal socket and
y a set-screw.

kinds of metals and alloys have been tried for the
olders in the enclosing globe; but the metal which
ls the heat of the arc best, and which is not deposited
side of the globe either in the form of dust or a brownish
ich unites with the glass and is not easily removed),
ther cast or wrought.

5. The *enclosing globe* is of the shape shown in Figs. 95 and 96. The pattern, open at both ends, can be more easily cleaned, whilst the other pattern possesses the advantage of having only one aperture to keep tightly closed, and is therefore more air-tight. In both patterns the edge of the apertures must be very evenly ground, so that special metal rings need not be attached. With these rings the arrangement is very difficult, owing to the unequal expansion of the glass and the metal, set up by the unavoidable variations of temperature.

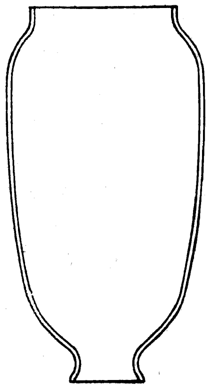

FIG. 95.

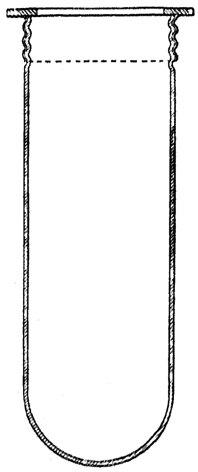

FIG. 96.

In Fig. 97 (Plate IX.) is shown the lower lamp mechanism of a British Thomson-Houston Co.'s "Drop Frame" lamp. The lower carbon and enclosing globe are held in a removable holder, and the outer globe is carried on a telescopic globe-lowering device. A quarter-turn of a bayonet catch allows the outer globe to be lowered and gives access to the inner globe and carbons. By loosening two thumbscrews the removable holder can be taken out and a fresh lower carbon and clean inner globe put in. The lower carbon and enclosing globe being clamped in, the

PLATE IX.

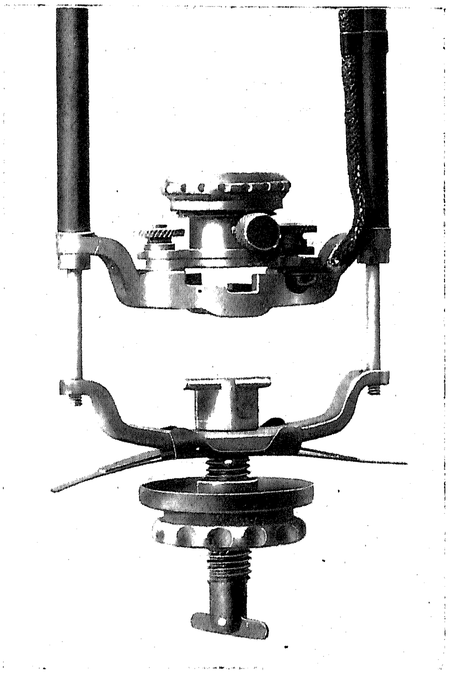

FIG. 97.

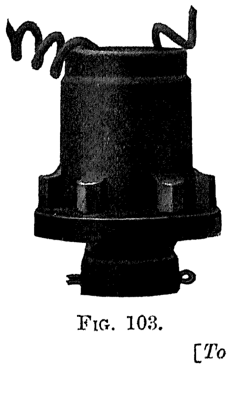

FIG. 103.

[To face page 104.

frame holder reduces the labour of trimming; and the outer globe, when lowered, is rigidly held by the sliding rods, and cannot swing. This makes this form of lamp suitable for street lighting and places exposed to high winds. Fig. 98 (Plate X.) shows the B.T.-H. Drop Frame lamp with the outer and inner globes together with reflector.

In the pattern of enclosure sealed at the bottom, the lower carbon holder must be so arranged that the former entirely encloses it. The enclosing globe must also be able to withstand the great changes of temperature produced when the lamp is switched on, without cracking. Enclosing globes which are only open at the top, are screwed to a gas cap, or globe cap, as it is sometimes called, an asbestos ring being inserted between (see Fig. 96). They may also be pressed against the cap, and held in place by means of a spring stirrup passing beneath the globe (Fig. 99). In the "Fixed Frame" lamp, shown in Figs. 104 and 105, it will be seen that the lower carbon is held by a rigid support within the enclosing globe, which is kept in position by a bail hung on two piston springs.

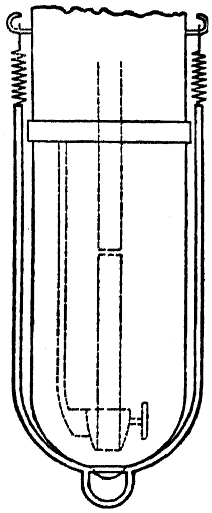

Fig. 99.

The gas cap surface, against which the enclosing globe rests, should be machined true and smooth in order to make the joint as nearly air-tight as possible. The cap must rest with a moderate pressure on the globe, otherwise it will result in cracking and chipping at the edge, with the obvious diminution in the life of the carbons. Moreover, this surface must be of a heat-resisting material, which also has high insulating properties. The finer grade of soapstone has been successfully used for this purpose. The gas cap is attached to the frame and is provided

with a central hole for inserting the upper carbon. If a side rod holds the lower carbon, and is fixed to the cap or frame, then the centre must have an insulated bushing of soapstone. The best practice seems to consist in making the gas cap of metal, with an insulated centre bushing for low tension lamps, and *vice versâ* in high tension lamps. The bushing is designed to give two requirements, one is that the upper carbon shall not have more than 0·3 mm. clearance, as the slightest increase would considerably shorten the period during which the carbon, could burn. The second requirement often made of this bushing is that it shall act as a relief valve for the explosion of gases in the inner globe. This is most necessary when the inner globe is closely screwed to the gas check, since this explosion takes place generally when the lamp is switched on after being out from seven to ten minutes, when, owing to the access of air, there is an explosive mixture inside the globe which would probably shatter it. In the Westinghouse lamp the bushings are arranged to have a slight vertical movement, allowing them to be lifted by the gases, in such a way as to open ports for equalizing the pressure with the atmosphere. In some makes of lamps another opening beside the central hole is adopted, to carry away the gases, and in others a valve instead of the simple opening is used, thereby preventing access of air. If the inner globe is only lightly pressed against the gas cap by means of a spring, then the valve and opening may be omitted.

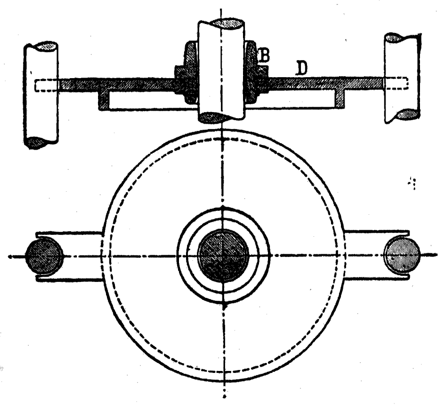

FIG. 100.

PLATE X.

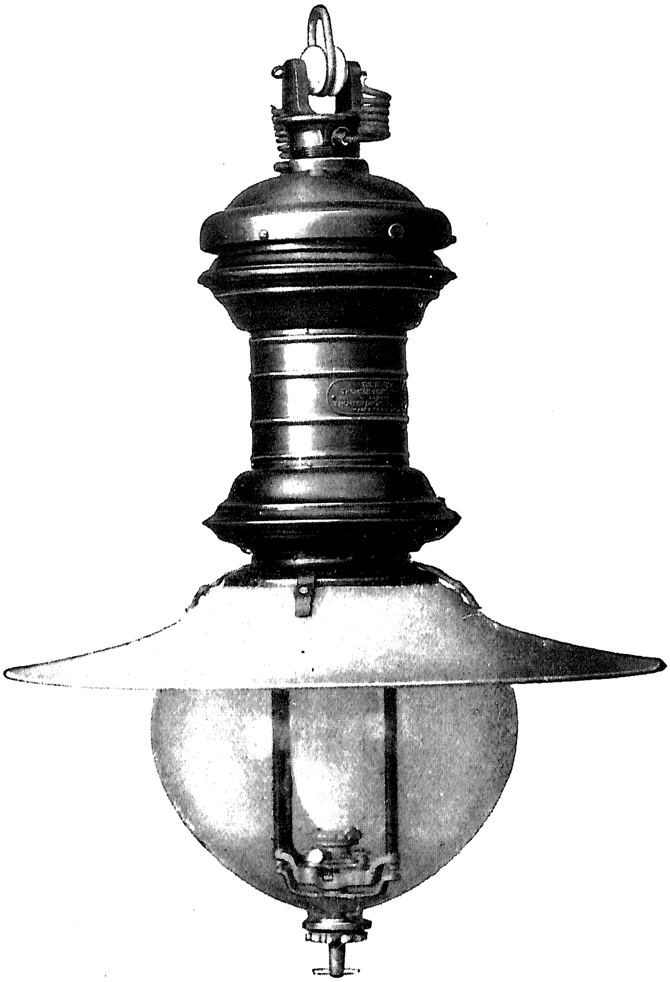

FIG. 98.

[*To face page* 106.

Inner globes, open at the top and bottom, are usually screwed to the lamp frame at the lower end, whilst at the top the gas cap can be carried loosely by the guide rods of the frame and rest upon the globe (Fig. 100) or be pressed down upon it by a spring. In the latter case the screwing of the bottom is unnecessary, as also the valve in the cap, provided, of course, that the latter is not attached to the globe so securely that it would burst before the cap lifted.

6. The *dashpot* is similar in construction to that of open arc lamps, except that in enclosed arc lamps it must be somewhat stronger in its action. This object may be attained by increasing either the size or the number of dashpots. In American enclosed arc lamps the cylinders are made of brass, and of as uniform a diameter as possible, the valve seats being accurately machined and the plungers fitted with care, so that each dashpot will operate in about the same time as every other one. And to prevent the plungers from jambing in the cylinder when the lamp is strongly heated, the former are made of graphite, which has practically a negligible temperature coefficient and satisfactorily prevents any sticking.

7. To adjust the current in some lamps, *adjusting springs or weights* are provided according to the particular construction. The former are fixed to one end of an adjustable screw pin. The latter may either be attached to the rocking lever in the form of small additional weights, or, as in the Westinghouse lamp, by a weight mounted on a threaded stud on the rocking or feed lever, and kept in position by a set-screw, thus permitting of a very accurate arc (or current) adjustment.

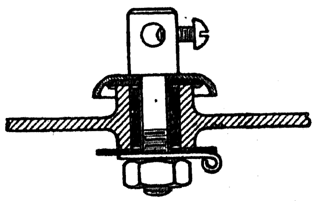

FIG. 101.

8. The *terminals* are similar to those shown in Figs. 41 and 42. American firms nearly always place the terminals

outside the lamps, on top of the casing. They are therefore petticoated to protect the insulation against deposits (Fig. 101).

9. The *lamp casing* may be the same as for open arc lamps. In order to attain a longer period of burning, it is desirable to protect the casing against the admission of air; on the other hand, the escape of gas and inside air must be facilitated owing to their expansion at high temperatures. For this purpose, one or two valves consisting simply of flat springs, cover openings in the casing. The casings for B.T.-H. lamps (Fig. 98) are made of solid copper in one piece. Three bayonet catches in the lamp top support the casing, and a single set-screw holds it rigidly. For the fixed frame lamps the casing is the same as the drop frame lamps, except at the lower end where the fixed frame casing is arranged to support the outer globe, which, in the drop frame lamp, is supported by the telescopic globe-lowering device. In the former, the outer globe is supported on a metal ring which fastens to the casing by bayonet joints, and hangs by a chain when the lamp is being trimmed. The upper and lower coronas of the casing give it a symmetrical appearance.

Outer globes may be either clear, opalescent, or alabaster. The lower opening may be omitted, except in so far as it is necessary for attachment, because in this lamp the ashes are already caught up in the inner globe, and it is rarely necessary to clean the outer globe. For streets, dockyards, and general outdoor lighting, where intense rather than steady light is required, opalescent inner and clear outer will give the best results. For interiors the opalescent or alabaster outer is to be preferred.

If both globes are opalescent, the movement of the arc is not so noticeable from the outside on account of the reflection between the two globes, although the loss of light is naturally considerable. Alabaster inner globes improve the quality of

PLATE XI.

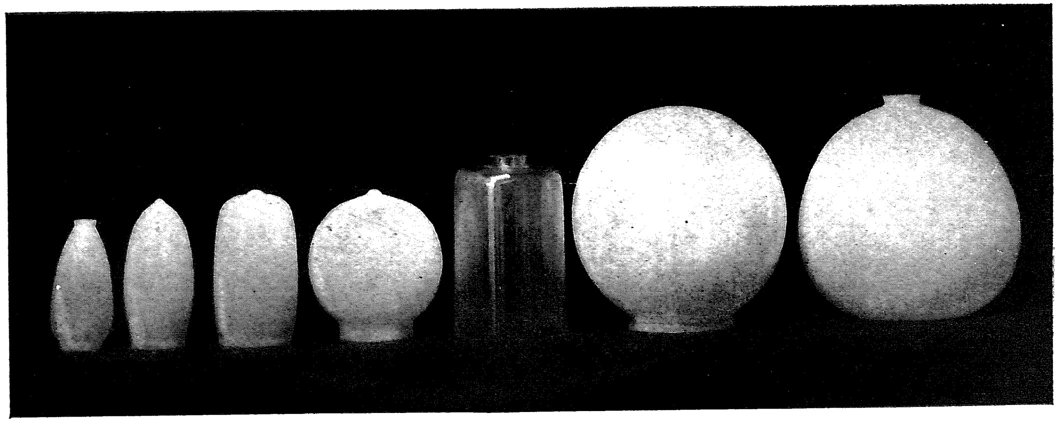

Fig. 102.

[To face page 108.

light, but do not resist heat as well as opalescent globes, which are more durable.

Sometimes the outer globe is dispensed with and the "inner" globe is made rather larger than usual. The spherical globe in Fig. 102 (Plate XI.), which, with a shade or a reflector, is very efficient, and concentrates the light in a downward direction, is such a single enclosure.* The first two globes are the usual enclosing globes, the third is for a twin carbon lamp, the fourth the above-mentioned single enclosure globe, the fifth is a cylindrical outer for drop frame lamps, the sixth an outer for fixed frame, and the last for drop frame lamps.

10. The *suspensions* are of two kinds, spring and hook. The former (Fig. 103, Plate IX.) consists of a highly insulated spring support fastened to the lamp by a cotter pin, and tapped for screwing on to a bracket. A spring absorbs vibrations, whilst the support keeps the lamp from swinging. The lead wires run through the support into the lamp.

The hook suspension (Fig. 98) is fastened to the lamp top in the same manner. It has two lugs carrying a porcelain insulator with a link for hanging the lamp on a hook.

C. DESCRIPTION OF ENCLOSED ARC LAMPS.

Fig. 104 indicates the new model Jandus lamp of Messrs. Drake and Gorham, which, whilst retaining the main features of the old pattern (one of the pioneers of enclosed lamps), embodies several improvements. The iron-clad magnet, armature, carbon holding frame, and enclosing globe are concentric to the central stem, ensuring correct alignment when assembling. The dashpot is placed on one side of the lamp for ease of access, and by means of a lever is geared to the armature mechanism in the ratio of 2 to 1, giving a powerful and quickly operating dashpot effect. The clutch is operated by a differentially wound solenoid, iron-clad,

* See also Fig. 104.

acting on an armature, which, together with its attachments, weighs nearly 3 lbs. The great inertia of this heavy weight naturally acts somewhat as a flywheel in steadying small fluctuations. The total weight of the mechanisms acts directly as a controlling force, and is therefore able to overcome any friction.

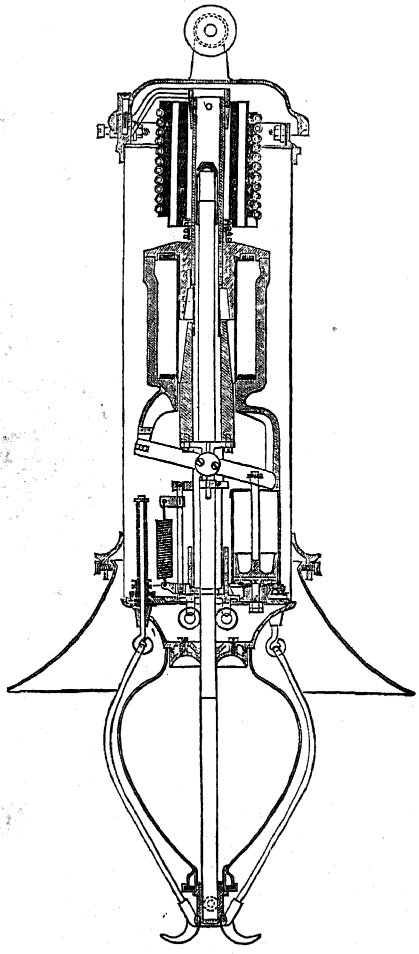

Fig. 104.

The upper carbon is held in a loose sheath and current is led to it by gravity brush rings, which give a smooth and frictionless contact, and thus avoid flexible cords. The negative carbon and enclosing globe are held by the negative carbon holder and inner globe holder, which are supported by the negative spring frame. The spring eyes of this frame are insulated from the body frame of the lamp and serve to carry current. The gas cap is made air-tight by machined metal facings to the lower part of the lamp body frame, which acts as a light diffuser.

The lamp has a self-contained resistance in the top of the lamp. The circuit through the lamp is as follows: current

passes from the positive terminal to inner end of the series coil, the outer end being connected under a screw in the iron body of the lamp. It then passes down body of lamp through the brush rings to upper carbon, from thence to the lower carbon and through negative holder, negative frame and

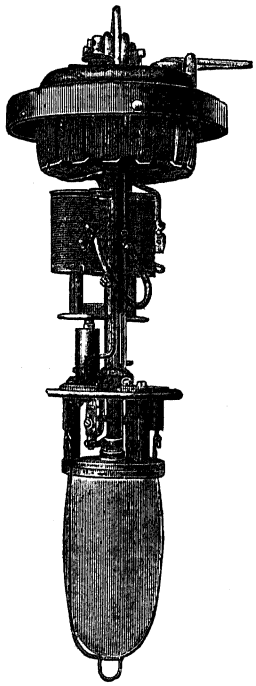

FIG. 105.

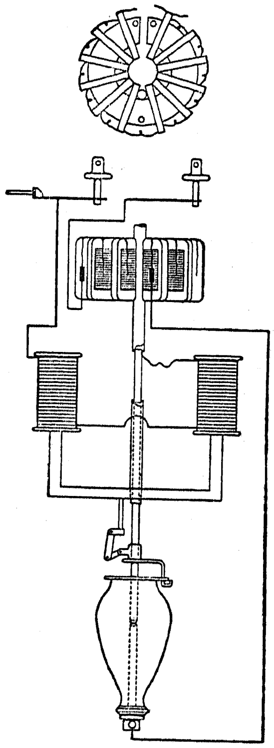

FIG. 106.

insulated spring eyes, thence to the resistance at the top of the lamp and to negative terminal. The shunt coil is connected across the arc, *i.e.* one end to the body of lamp and other end to the spring eyes. The resistance of the shunt is about 600 ohms. A life of 125 hours is claimed with a single pair of carbons.

Fig. 105 is a multiple lamp of the series type for alternating current circuits of the American General Electric Co., with scheme of connections in Fig. 106. Fig. 107 (Plate XII.) shows a B.T.-H. multiple lamp for continuous current circuit with scheme of connections in Fig. 108. It will be noted that for direct current an adjustable resistance, and for alternating current an adjustable choke-coil, for adjusting the arc voltage, are introduced. An adjusting clip (Fig. 110) effects the adjustment on this resistance (Fig. 109), which consists of bare resistance wire wound on a porcelain drum, with each turn in a separate groove, so that it is impossible for the turns to be short-circuited. The choke-coil (Fig. 111) is made with a laminated iron core and with separate former wound coils, so that more or less turns can be connected. In Fig. 108 the lamp has adjustment for two current capacities, 5 or $4\frac{1}{2}$ amps. To adjust the lamp for its higher current rating, connect the wires A and B to the lower loops of the series magnets.

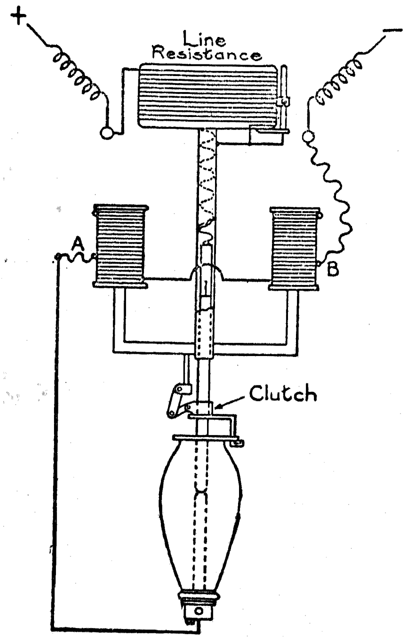

FIG. 108.

Fig. 112 shows the shape of the magnet core for alternating current. To it is attached a flat spring which is fastened to the clutch lever. This spring neutralizes the vibrations set up in the core by the pulsation of the alternating current, and thus prevents a simultaneous vibration of the other parts of the lamp.

PLATE XII.

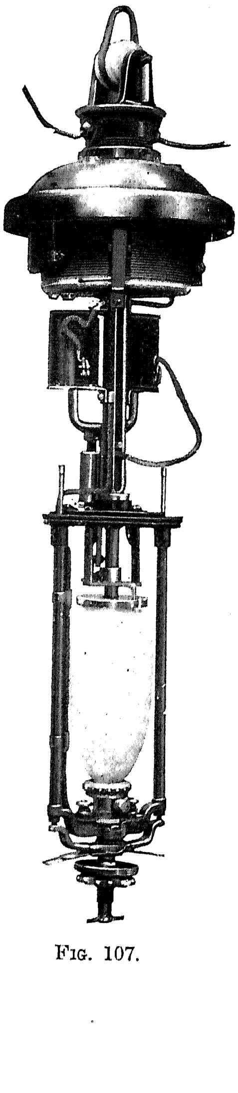

Fig. 107.

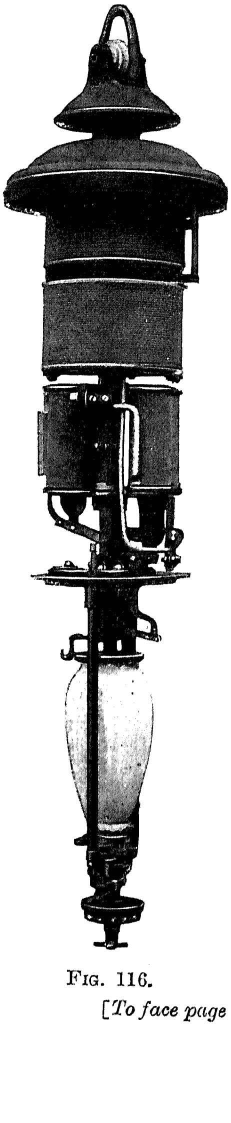

Fig. 116.

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The plungers of the dashpots are made of graphite, and the cylinder is provided with a ball-valve which closes when the arc is struck and opens when the carbon tips approach.

Fig. 113 is a series multiple lamp of the American General Electric Co. for continuous current, and Fig. 114 for alternating current circuits; both of the differential feed type, with

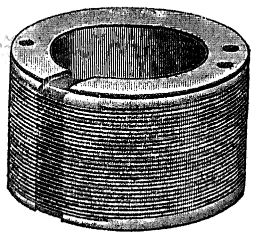

Fig. 109.

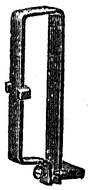

Fig. 110.

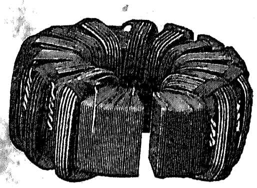

Fig. 111.

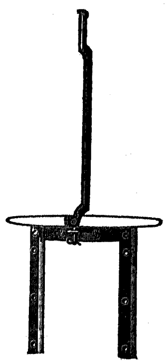

Fig. 112.

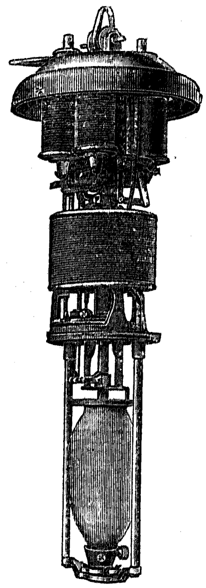

Fig. 113.

the shunt and series magnets mounted in pairs on opposite side of the central tube. The continuous current lamp is made in two forms, one with steadying and substitutional resistances inside the lamp, and the other with the steadying resistance external to the lamp. Fig. 113 represents the latter. Fig. 116 (Plate XII.) is a differential lamp of the British Thomson-Houston

Co., showing the self-contained steadying and substitutional resistances, and Fig. 116A is a scheme of its connections. In case of failure of the arc, the substitutional or compensating resistance is introduced by the automatic mechanical cut-out attached to the feed lever. This cut-out operates if an excessive current passes through the shunt coils and closes with a

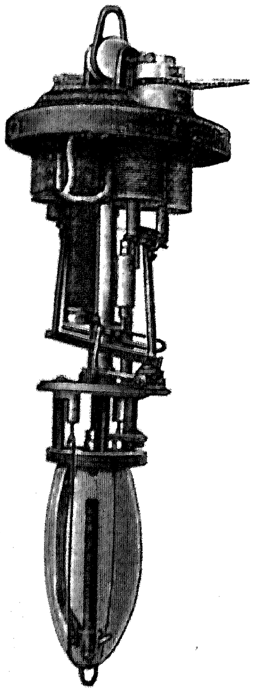

FIG. 114.

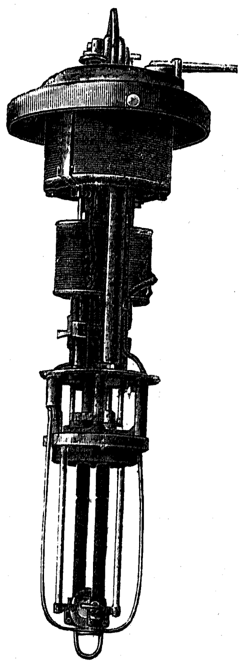

FIG. 115.

positive action in case of an interrupted circuit through the series coils. Inclined contact surfaces are used to prevent trouble from accumulation of dirt. The turns of the series coils are arranged for the smallest current, and shunted across them is an adjustable resistance. In this way the lamp current may be altered without any alteration of the magnetic

PLATE XIII.

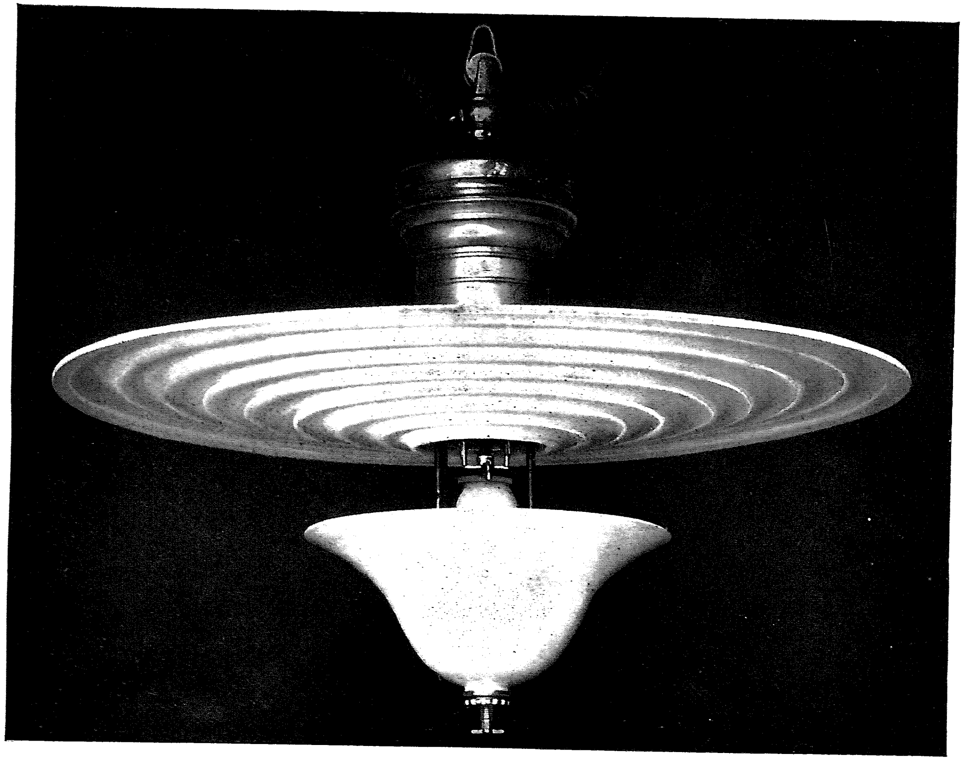

Fig. 117.

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conditions, so that a simple adjustment of the lamps working in series, or an increase of lamp current may be obtained.

The twin carbon lamp in Fig. 115 works with the two arcs in series, each of 80 volts pressure and intended for a 200 to

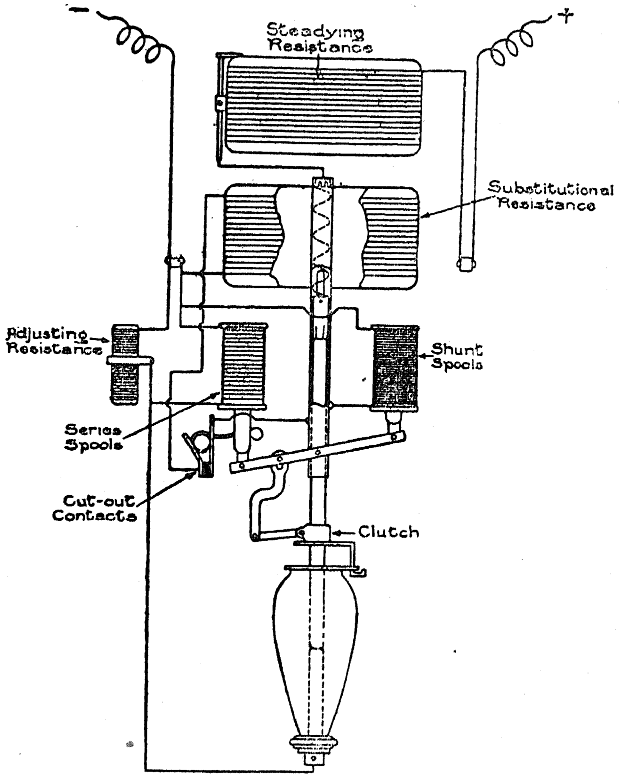


FIG. 116A.

250 volt circuit. The object of this is a better lighting effect than with one arc of 150 volts pressure and the same current. In many cases it shows advantages over the two single lamps in series, especially for shop and office lighting. In cases where the supply has been changed from 100 to 200–250 (continuous

current) they can be used without changing the wiring or arrangement.

Figs. 117 and 118 (Plates XIII. and XIV.) show a lamp for indirect lighting with a Concentric Light Diffuser above the arc-enclosing globe. This diffuser is made of metal with a curved reflecting surface, by which a particularly favourable dispersion of the rays is obtained. Beneath the globe is a white glass shade which permits a little light to pass through. This diffuser is useful for drawing-offices, etc.

All the American lamps are provided with a single pole switch, mounted on the lamp top, and intended to be switched back and forth by a long pole in the hands of a janitor. It consists of a blade made entirely of insulating material with a contact button inserted in it which is forced between two stationary contacts to close the circuit.

There still remains to be mentioned the construction of an enclosed arc lamp for direct or alternating current in which no magnets are used. In their place the expansion of a hot wire serves both to strike the arc and to regulate the feed. Figs. 119 and 120 show the principle of such a lamp ("Foster" System).

In this lamp a bar, c, one end, c_1, of which rests in a pivot, has its other extremity, k, fastened to the levers j_1, j; the latter bent lever, j, works a clutch. To the extremity k are also attached the hot wire d and the spring g, and as the spring expands or contracts the point k is deflected to the right or left. The lever is so arranged that if no current passes through the wire or lamp the clutch liberates the upper carbon and allows it to make a contact with the lower one. On switching on the current, d expands, g pulls k to the left, and the lever j lifts up the clutch and hence the upper carbon, so that the arc is struck. The play between the tension of the spring g and the wire regulates the separation of the carbons.

PLATE XIV.

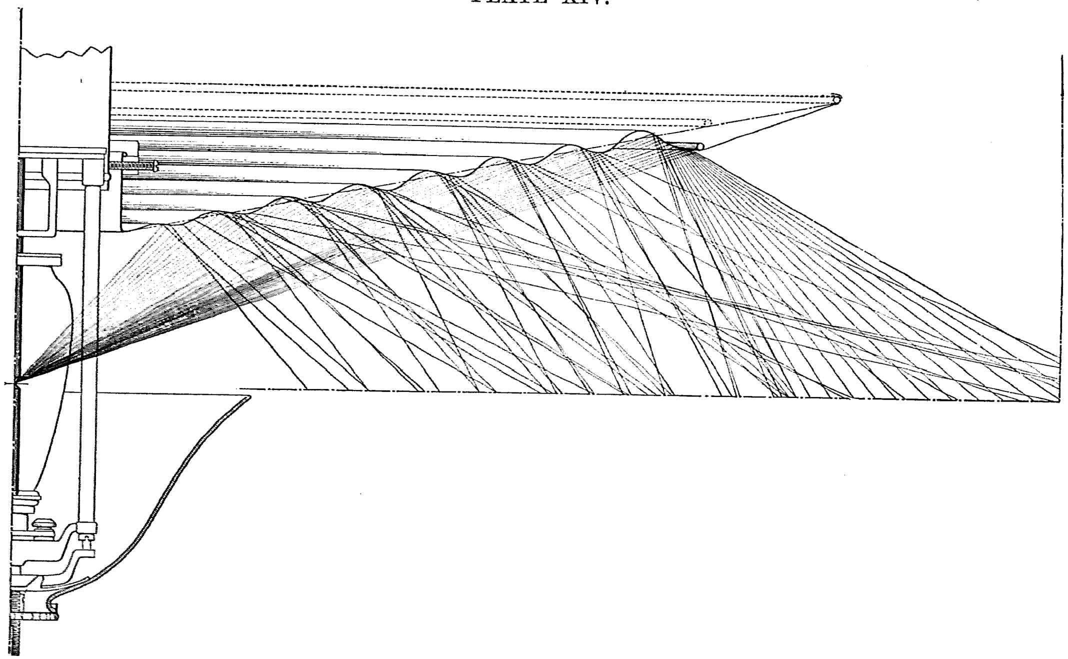


FIG. 118.

[*To face page* 116.

Fig. 121 (Plate XV.) shows the construction of the lamp. The hot wire d_1 is attached to the hook k, and by means of the balance beam R transmits its expansion to the hot wire d, which is fastened at its lower end to rod c. At F on the rod c the lever J is adjusted by means of two nuts, so

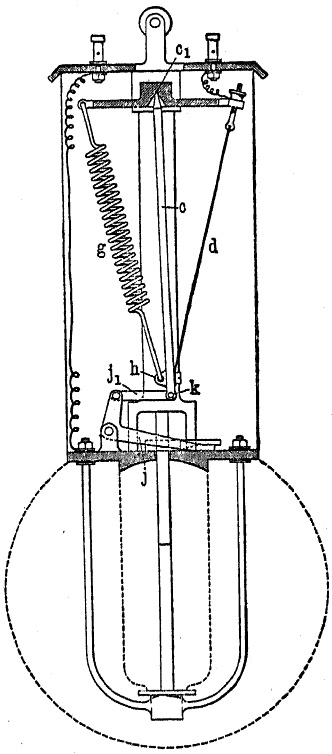


FIG. 119.

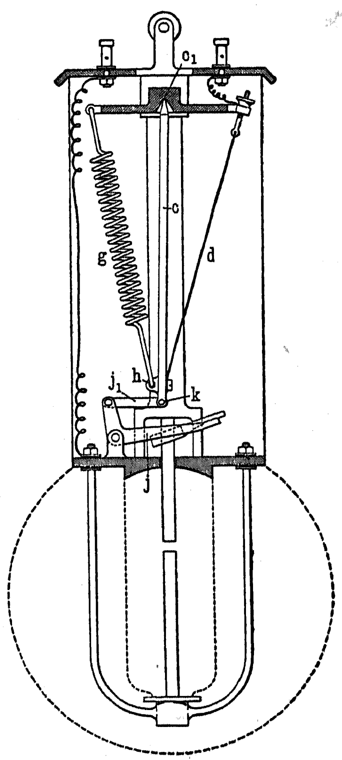


FIG. 120.

that the release of the clutch or the lamp current may be regulated. The spring g grips the lever in the immediate neighbourhood of the rod c.

The durability of such a lamp depends above all things upon the durability of the hot wire. Since absolute constancy

cannot be obtained, an occasional renewal of the wire is necessary. This lamp requires no dashpot, and can be used with direct and alternating current without any further mechanism.

D. CARBONS FOR ENCLOSED ARC LAMPS.

The carbons used in enclosed arc lamps must be of a quality especially suited to them. They must produce little ash and must not crack easily, as both these faults produce a very unsteady light. With direct current lamps, two solid carbons are used, whilst with alternating current, cored carbons are more suitable. The latter, because the long arc produced by alternating current, especially with the variation of the mains pressure, is easily broken. This is avoided by the better conductivity of cored carbons. The stub of the upper carbon, for direct current, may be used as a lower carbon when trimming the lamp.

SIZES OF CARBONS AND LAMP PRESSURES FOR DIRECT CURRENT ENCLOSED ARC LAMPS.

TABLE XI.

Current in amps.	Lamp pressure in volts. (about)	Solid carbons.				Period of burning in hours. (about)
		Upper.		Lower.		
		Diameter in mm.	Length in mm.	Diameter in mm.	Length in mm.	
4	70–75	10	300	10	150	90–100
5	75–80	13		13		130–150
6	80	13		13		110–120

The period of burning given is for periods of five hours at a time. If the lamp is burnt continuously the period for a

PLATE XV.

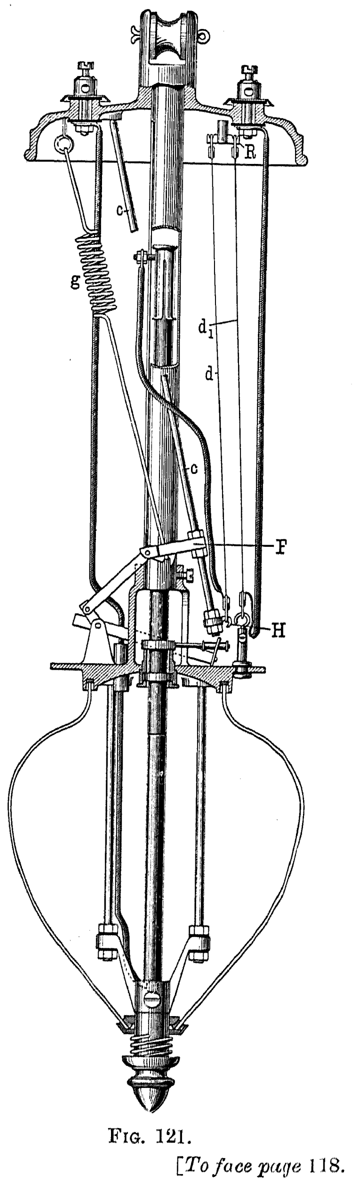


FIG. 121.

[*To face page* 118.

single pair of carbons is longer by about 30 per cent. than that given in Table XI.

SIZES OF CARBONS AND LAMP PRESSURES FOR ALTERNATING CURRENT ENCLOSED ARC LAMPS.

TABLE XII.

Current in amps.	Lamp pressure in volts. (about)	Carbons.				Period of burning in hours. (about)
		Upper (cored).		Lower (cored).		
		Diameter in mm.	Length in mm.	Diameter in mm.	Length in mm.	
6 7 8	70	13	220	13	140	60 50 40

CHAPTER IV

LIGHT INTENSITY, LIGHT DISTRIBUTION, AND THE APPLICATION OF THE ELECTRIC ARC FOR PURPOSES OF ILLUMINATION

I. LIGHT INTENSITY AND LIGHT DISTRIBUTION

IN spite of the efforts of the International Electrical Congress and other Congresses there is at present no international convention with reference to the unit of luminous intensity, nor a practical standard in general use. In 1896 this Congress proposed the bougie décimale * as the unit, but though its relation with common flame standards has been determined with some precision, it has never come into universal application.

The legal standard in English-speaking countries is the sperm candle, which burns 120 grains (7·776 grams) of spermaceti per hour. This legal unit is spoken of as the "standard candle," and is said to give a luminous intensity of one candle-power. It comes nearer to being an international unit than any other standard.

* The bougie décimale is one-twentieth of the Violle standard, which is the luminous intensity emitted, normal to its surface, by one square centimeter of molten platinum at its solidifying temperature.

The official standard for testing gas in London, also recently adopted by the National Physical Laboratory, Bushy House, is the Harcourt lamp,* burning pentane, and of a candle-power of 10 legal candles.

The Hefner lamp † used in Germany, and so often employed in other countries for purposes of reference, burns amyl acetate.

The Carcel standard, is a colza lamp of fixed form, and is used in France and Italy.

The Hefner lamp is simpler in construction than the pentane, small, and more easily set up, but the flame of the pentane is easier to adjust. Moreover, a weak point with the Hefner lamp is its colour, being distinctly reddish orange, whereas the pentane is much whiter.

Expressing the values of the units in terms of that of the legal candle, we have ‡—

Pentane.	Hefner.	Carcel.	Bougie décimale.
1 or 10	0·922	0·992	1·03

The light intensity of an arc lamp in a certain direction can be measured by a photometer by comparing its illuminating power of the photometer screen with that of a standard light intensity. The illuminating power measured is the amount of light received per unit area of photometer surface placed at right angles to the rays.

If we imagine a source of light at the centre of a hollow sphere of unit radius and emitting light equally in all directions, then it is evident that the ratio of the quantity of light received on an area, S, of the unit sphere to that of the whole sphere is

* For description see "The Notification of the Gas Referees for the Year 1904," published by Eyre and Spottiswoode.

† For description see the *Elektrotechnische Zeitschrift*, vol. iii. p. 445, and vol. v. p. 20.

‡ C. C. Paterson, *Journal Inst. E. E.*, January, 1907. See also footnote Appendix I.

equal to the ratio of the solid angle, ω, enclosed by the surface, S, to the solid angle, 2π, enclosed by the sphere.

The surface enclosed by the solid angle $2\pi = 4\pi \times 1^2$, since the radius is unity.

Hence—

$$\frac{\omega}{2\pi} = \frac{S}{4\pi}$$

Therefore—

$$\frac{\text{The quantity of light received on S}}{\text{Total quantity of light emitted}} = \frac{S}{4\pi}$$

or—

$$\frac{\text{Quantity of light received on S}}{S} = \frac{\text{Total quantity of light emitted}}{4\pi}$$

$$\text{Illuminating power} = \frac{\text{Total quantity of light emitted}}{4\pi}$$

This illuminating power is equal in all directions in the above case. In the case of an arc lamp which has a different intensity in different directions, the mean illuminating power would be the total quantity of light given out divided by 4π. This mean is called the *mean spherical candle-power*. The unit M.S.C.P. is the quantity of light emitted by the standard candle in a unit angle, *i.e.* it is the amount falling on unit surface placed at right angles to the horizontal rays at unit distance.

The light efficiency of the arc is obtained by dividing the total quantity of light emitted by the electrical energy absorbed. It is therefore conveniently expressed as M.S.C.P. per watt. As we are concerned mostly with horizontal illumination in exterior and interior lighting, the quantity—*mean hemispherical candle-power*—is more generally taken. It is the mean illuminating power for the lower hemisphere of unit radius. The light efficiency is then expressed as M.H.C.P. per watt.

The light intensity of all arc lamps depends upon the current, the P.D. across the arc, the quality of carbon, the diameter and position of carbons, the supply of air to the arc,

the degree of transparency of the globe, and other circumstances. The light intensity increases with the strength of current, and

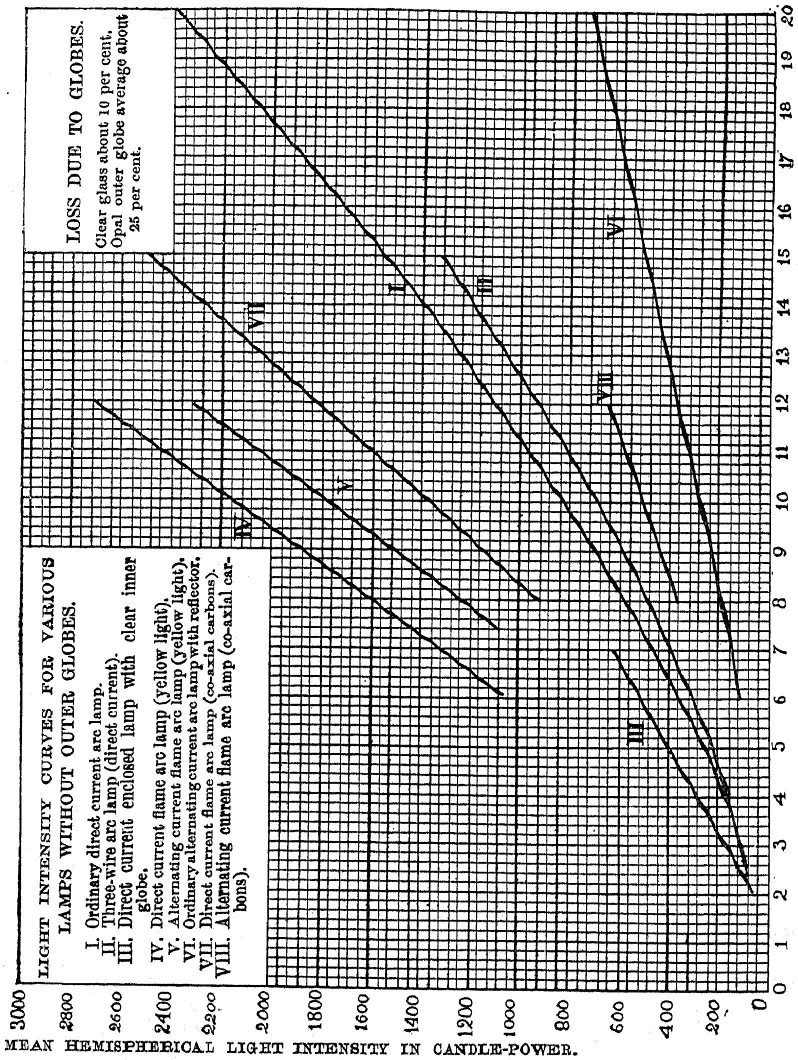


FIG. 122.

at the same time the light efficiency of the lamp increases

to a greater extent. In Fig. 122 are plotted light intensity curves, showing the relation between the M.H.C.P. of various lamps without outer globes, and different current values. On the other hand, the efficiency diminishes with the increase in length of arc (viz. P.D.), but to a less extent. The efficiency increases somewhat on increasing the P.D., starting with a very

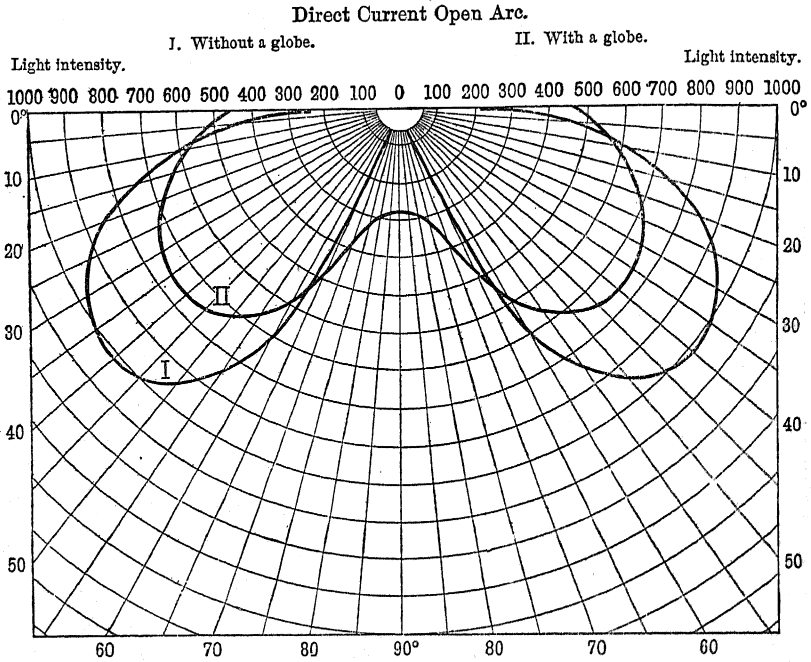


Fig. 123.

short arc, but soon reaches a maximum. For, although more light is exposed by the crater, a large absorption takes place in the carbon mist which it traverses.* The efficiency of arc lamps is diminished somewhat when worked in series, on account of the extra power spent in the steadying resistance.

The effect of the quality of commercial carbons upon the

* Mrs. Ayrton, "The Electric Arc," p. 345.

intensity of the light, apart from its steadiness, consists mainly in the irregular formation of the carbon tips with inferior qualities (*i.e.* a smaller angle of distribution), and in the dirtying of the globe due to large deposits of ashes. With treated carbons (as in the flame arc lamp) the light intensity is considerably increased, in spite of the increased deposit of ashes.

Alternating Current Open Arc.

I. With reflector but without a globe. II. With a globe.

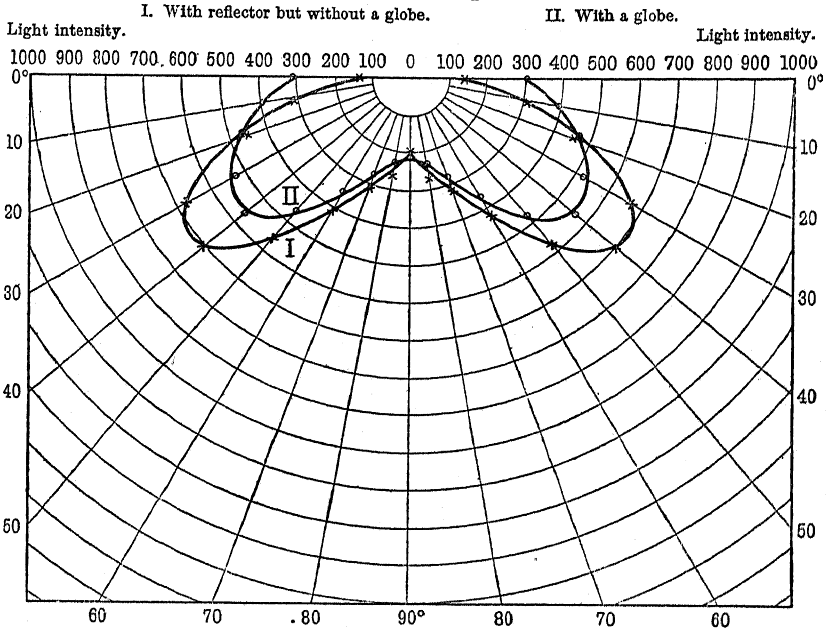


Fig. 124.

With increased diameter of the carbons the light intensity is diminished, on the one hand, because, in consequence of the increased surface (increased heat radiation), the carbon tips glow for a shorter distance, and on the other hand, because the angle of distribution becomes smaller. With an increase of oxygen the burning of the carbons is increased per unit of time, and hence the temperature of the tips, and hence also the

light intensity, are increased. But since the increased admission of air depends in arc lamps mainly upon ventilation, so also is the heat radiation somewhat greater. The mechanism of the lamp itself has only a secondary influence upon the light intensity, and shows itself mainly in the steadiness of the light.

For most purposes only the hemispherical light intensity and

Direct Current Flame Arc with vertical, co-axial carbons.

I. Without a globe. II. With a globe.

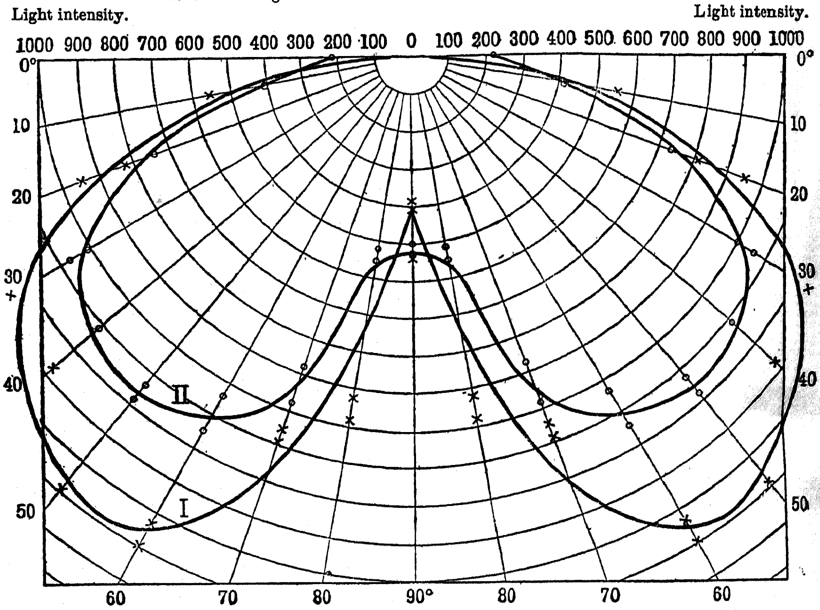


FIG. 125.

the light distribution of the arc are of practical interest. The characteristics of the latter are shown in Figs. 123 to 132. These polar curves indicate by their radii vectors the different light intensities in different directions. The light intensities are in Hefner units, and to reduce them to English standard candles, the values must be multiplied by 0·92.

Alternating Current Flame Arc with vertical, co-axial carbons.

I. With reflector and without a globe. II. With reflector and with a globe.

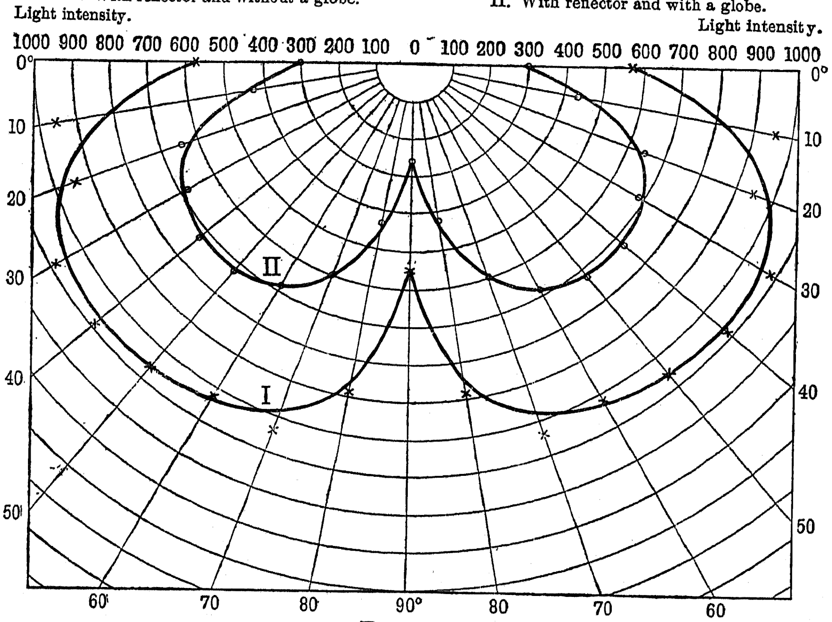


Fig. 126.

TABLE XIII.

Fig.	Supply.	Type of arc.	Position of carbons.	Globe.	Further details.
123 (i.)	D.C.	Open	Vertical (co-axial)	Without	—
" (ii.)	"	"	"	With	—
124 (i.)	A.C.	"	"	Without	With reflector
" (ii.)	"	"	"	With	
125 (i.)	D.C.	Flame	"	Without	—
" (ii.)	"	"	"	With	—
126 (i.)	A.C.	"	"	Without	With reflector
" (ii.)	"	"	"	With	
127 (i.)	D.C.	"	Inclined	Without	No blow-down magnet
" (ii.)	"	"	"	With	
128 (i.)	A.C.	"	"	Without	—
" (ii.)	"	"	"	With	—
129	D.C.	Enclosed	Vertical (co-axial)	Inner	No outer
130	"	"	"	Opalescent inner	Alabaster outer
131	A.C.	"	"	Clear or transparent inner	With reflector
132	D.C.	"	"	With small opalescent oval globe	2·2 amps., 65 volts, 4 mm. cored carbons

It may be seen from the curves that the distribution is not uniform, though not at all disadvantageous to the illumination.

Direct Current Flame Arc with inclined carbons.

I. Without a globe and no blow-down magnet.

II. With a globe and no blow-down magnet.

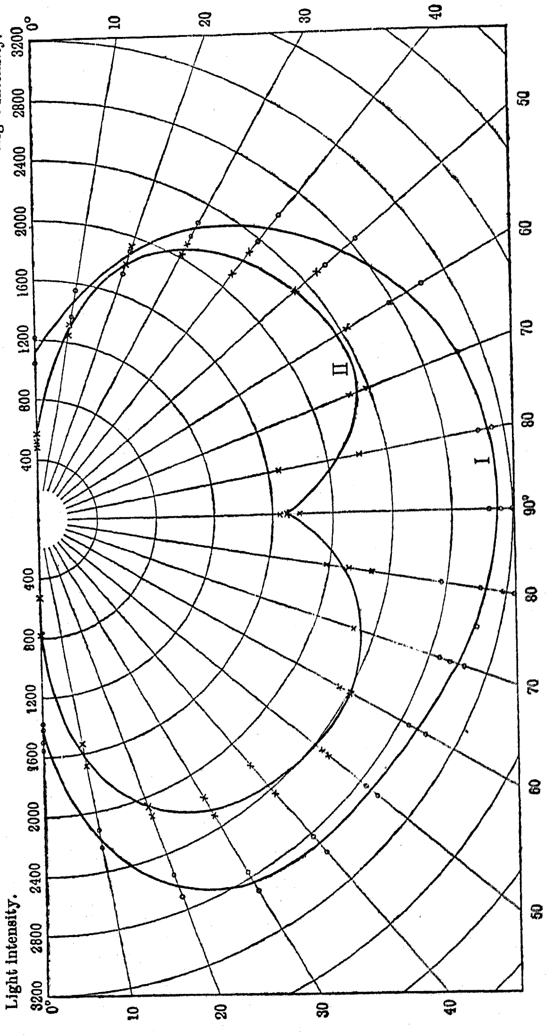


FIG. 127.

Lamps contain the greatest light intensity within an angle of 20° to 70° below the horizontal. Only flame arc lamps with

inclined carbons differ in this respect and possess, without a globe, a maximum angle of 90° below the horizontal. The polar curves of Figs. 124, 126, and 131 only appear in alternating current lamps provided with a reflector. The polar curves of lamps with co-axial carbons may be imagined as the cross-section of a surface of revolution with the vertical as axis, which conception does not apply quite to lamps with inclined carbons. In alternating current flame arc lamps with

Alternating Current Flame Arc with inclined carbons.

I. Without a globe. II. With a globe.

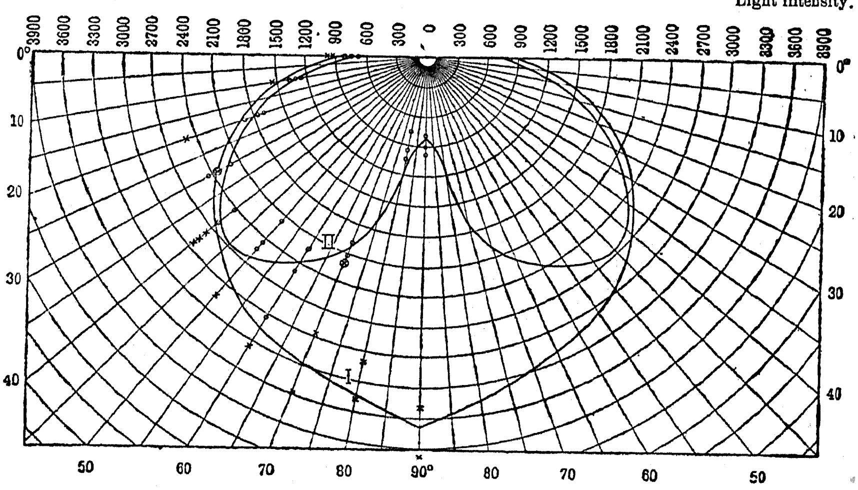


FIG. 128.

inclined carbons, a particular value of the light intensity on one side of the axis of rotation possesses an equal value on the other side (Fig. 128), whilst with the corresponding direct current flame arc lamps the distribution of the light is somewhat unsymmetrical, because the positive carbon emits more light than the negative (Fig. 127). The influence of the globe is felt, not only in a loss of light, but also in a certain reduction of the maximum and minimum of the light intensities, and

gives, therefore, a more uniform distribution of light. By the use of an opal cylindrical inner globe and an alabaster outer globe, as is usual with enclosed arc lamps, the maximum distribution of light occurs usually at a somewhat smaller angle below the horizontal than is the case with a single enclosing globe (compare Figs. 130 and 132). The inward bending of the

Direct Current Enclosed Arc.

With inner globe and no outer.

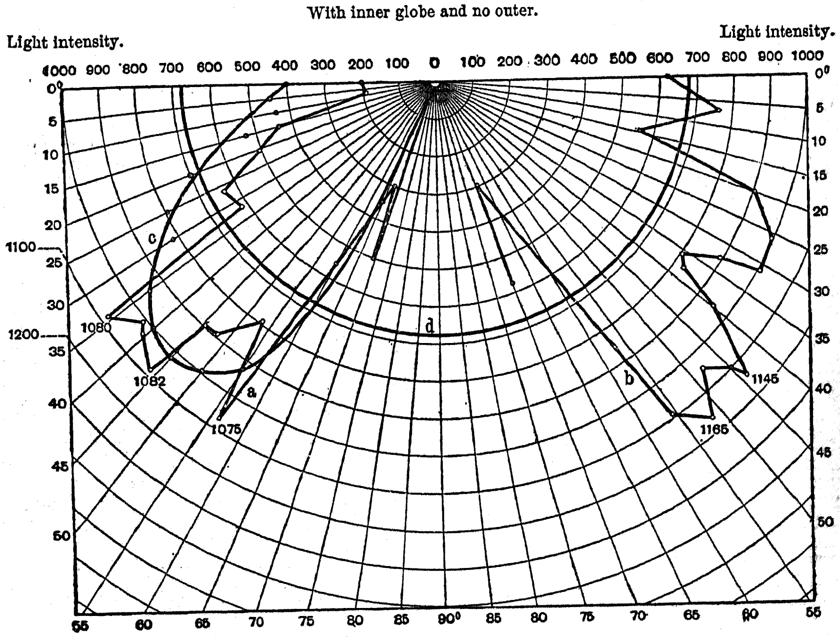


FIG. 129.

curves II. in Figs. 127 and 128, to the vertical, is due to the presence of the ash tray in the lamps during photometric observations.

It has been stated that the lighting power of an arc lamp is given in mean hemispherical candle-power, *i.e.* the candle-power which would occur if the light below the horizontal were uniformly directed towards a hemispherical surface. This light

intensity is used to calculate the necessary number of lamps for a given illumination. With the ordinary vertical carbons, the

Direct Current Enclosed Arc.

With opal inner and alabaster outer globes.

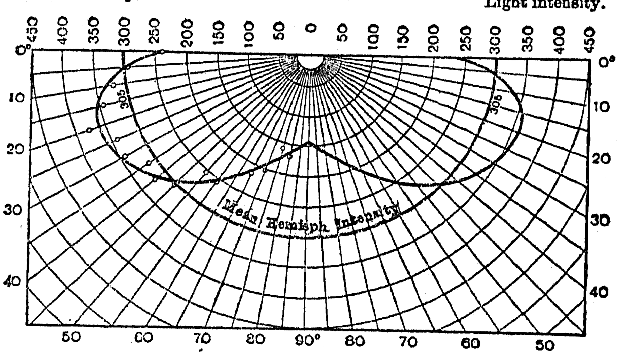


Fig. 130.

Alternating Current Enclosed Arc.

With clear inner globe.

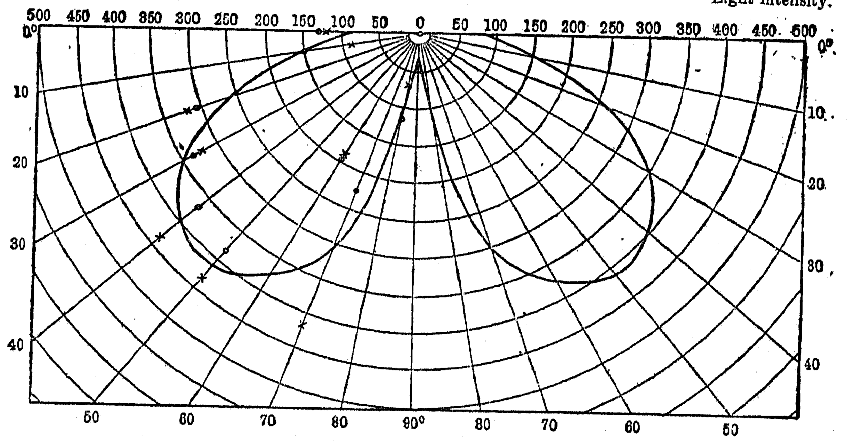


Fig. 131.

light emitted is fairly symmetrical round the vertical axis, and the determination of the mean hemispherical candle-power from

the polar curve may be obtained by Rousseau's method. In the polar diagram (Fig. 133), a quadrant is drawn, and the inter-

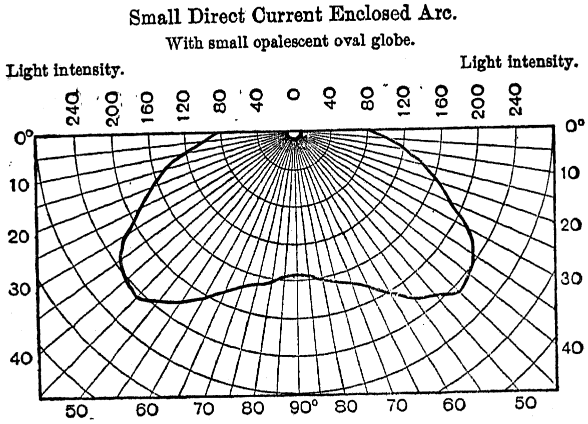


FIG. 132.

sections 1, 2, 3, 4, etc., of the radii vectors are projected on the co-ordinate axis OY of a rectangular co-ordinate system, the

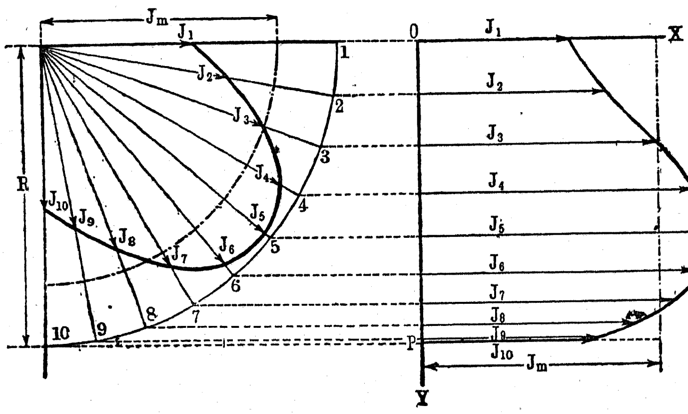


FIG. 133.

length of the ordinates J_1, J_2, J_3, etc., being made equal to the light intensities in the directions $J_1 1$, $J_2 2$, $J_3 3$, etc. The

locus of the extremities of the above ordinates encloses with OX and OY an area, the mean ordinate of which gives the mean hemispherical candle-power. As a matter of fact, the quantity of light received by the hemisphere (of radius R) $= 2\pi R \times$ Area of the Rousseau surface.*

Hence the mean quantity of light received per unit area of the hemisphere, *i.e.* the mean hemispherical illuminating power,

$$= \frac{2\pi R \times \text{Area of Rousseau's surface}}{2\pi R^2}$$

(Since $2\pi R^2 =$ area of hemisphere)

$$\therefore \text{ Mean hemisph. c.p.} = \frac{\text{Area of Rousseau's surface}}{R}$$

$$= \frac{\text{Area of Rousseau's surface}}{OP}$$

the scale of ordinates being that of standard candles.

In Fig. 122 are plotted the mean hemispherical candle-powers of various lamps for different currents.

It must be noted here that in alternating current flame arc lamps, with super-imposed and with inclined carbons, the consumption of watts in the arc is less than the product of current and lamp pressure. The power factor is 0·85 to 0·9, although the current and arc P.D. are practically in phase. The power factor is less than 1, because at the maximum current value (at every pulsation), the conductivity of the arc, owing to an increased heating of the carbons and the generation of a greater quantity of conducting vapour, becomes so great that the decrease in P.D. in the arc is less at that moment than before or after the maximum value of the current. The terminal pressure, therefore, shows during each current pulsation two maximum values, *i.e.* a bending in of the P.D. curve when the maximum value of the current occurs.

* See Mrs. Ayrton, "The Electric Arc," p. 454.

The lamp pressure is about equal in direct and alternating current flame lamps with inclined carbon. Hence, taking account of the power factor, the consumption of energy of a 10-amp. alternating current flame lamp is not greater than that of an 8·5- to 9-amp. direct current flame lamp. The quantity of light is, therefore, as may be seen from Fig. 122 almost equal.

On the other hand, in all lamps with super-imposed carbons, the quantity of light, with equal consumption of energy in the arc, is considerably less with alternating current than with direct current. The lower carbon tip, with alternating current, emits just as much light above the horizontal as the upper carbon emits below, whereas, with direct current, by far the most light is emitted by the positive carbon. The light directed upwards is only partly reflected by the reflector and is partly absorbed by it.

There are, however, clearly other factors which determine the lower candle-power per unit of energy of the alternating current arc in comparison with the direct current arc. The power factor of the usual alternating current arc is approximately 1. Also, neglecting the greater loss owing to the presence of two globes, the candle-power is less in enclosed arc lamps than in lamps with an open arc and an equal consumption of energy.

The values of the mean hemispherical intensity given in Fig. 122 are, of course, only approximate, because, as already mentioned, many circumstances may influence the absolute value. In using these values the loss due to the use of an outer globe must not be neglected.

II. ILLUMINATION.

In planning out lighting schemes for outdoor work the general principle followed is to obtain the most intense and, at the same time, uniform horizontal illumination. This will be better attained the more lamps there are and the higher they

are placed above the surface to be illuminated. But with an increased number of lamps the initial outlay and the cost of maintenance increase; moreover, with regard to the height at which the source of light is fixed, an influencing factor is that the illumination diminishes owing to the increased distance.

For street work and the lighting of such places as railway stations, ground illumination is not the only consideration, the illumination of side walls being also important. In the case of suburban road lighting the lamps must act as beacons to mark out the road.

In the lighting of interiors other factors, such as the colour of the walls, ceiling, and object to be illuminated are of influence. The brighter the walls and the ceiling, the better and the more uniform will the illumination be, because with a reflection from a bright surface there is not only a less loss of light (*i.e.* less absorption), but also a more uniform distribution of the rays.

On page 122 we have seen that the total quantity of light, Q, emitted by a luminous point is 4π times its mean illuminating power. The unit illuminating power being the candle-power we have—

$$Q = 4\pi \times \text{c.p.}$$

This quantity Q falling equally in all directions on a sphere of radius R would produce an illumination of $\frac{Q}{4\pi R^2}$ (*i.e.* quantity of light per unit surface).*

Hence—

$$\left.\begin{array}{c}\text{Illumination on sphere}\\ \text{of radius R}\end{array}\right\} = \frac{Q}{4\pi R^2} = \frac{4\pi \times \text{c.p.}}{4\pi R^2} = \frac{\text{c.p.}}{R^2}$$

The intensity of illumination is therefore proportional to the intensity of the light source, and inversely proportional to

* Note that the unit surface is at right angles to the rays.

the square of the distance of the light source from the surface to be illuminated. This will be true if the surface is perpendicular to the rays emitted by the source. If the surface is inclined to the rays so that the angle of inclination of the rays and the perpendicular to the surface be α; then, since the quantity of light received on the smaller projected area of the surface, when viewed from the source of light, is the same as that received by the surface, it follows that the illumination of the surface must diminish as this projected area decreases. This area varies with cosine α. The general formula for illumination becomes—

$$\frac{\text{c.p.}}{\text{R}^2} \cdot \cos \alpha$$

The unit of illumination is that obtained by unit light intensity (*i.e.* the candle-power) upon a unit surface placed at a unit distance perpendicular to the rays.

In England, the unit distance being the foot, the unit chosen is that produced by a standard candle at 1 foot, and is conveniently called the *candle-foot.*

The unit of illumination in Germany is the *Hefner-metre*, or *Lux*,* and is self-explained by its name. In France the unit is the *Carcel-metre*. The following table shows the relation between them :—

1 candle-foot equals	1 Hefner-metre, or Lux, equals	1 Carcel-metre equals
11·7 Hefner-metres, or Lux 10·85 Carcel-metres	0·0855 candle-foot 0·928 Carcel-metre	0·0922 candle-foot 1·08 Lux

$$\text{And since 1 Lux} = 0{\cdot}0855 \text{ candle-foot}$$

$$\text{Illumination} = \frac{\text{c.p.}}{\text{R}^2} = 0{\cdot}0855 \text{ candle-foot}$$

$$\therefore \text{R} = \sqrt{\frac{\text{c.p.}}{0{\cdot}0855}} = \sqrt{11{\cdot}7 \times \text{c.p.}} \text{ feet}$$

* See Appendix I. Photometric quantities.

If c.p. = 1, then R = 3·42 feet. That is, the Lux is produced by an English standard candle at a distance of 3·42 feet.

In Fig. 134 J is a source of light of candle-power J at a height a above the ground.

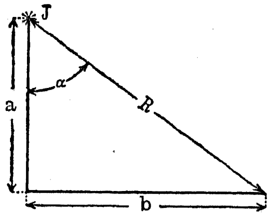


FIG. 134.

The ground or horizontal illumination at unit surface distant b from the pillar or vertical a is equal to $\frac{\text{J} \cos \alpha}{\text{R}^2}$ candle-feet, where R in feet is the slant distance from the source of light and α the angle which the rays make with the normal to the surface. Also $b = a \tan \alpha$.

The horizontal illumination becomes—

$$\frac{\text{J} \cos \alpha}{a^2 + b^2} = \frac{\text{J} \cos \alpha}{a^2 + a^2 \tan^2 \alpha}$$
$$= \frac{1}{a^2} \times \frac{\cos \alpha}{1 + \tan^2 \alpha} \times \text{J}$$
$$= \frac{1}{a^2} \times \cos^3 \alpha \times \text{J candle-feet}$$

or without reference to the angle of inclination α—

$$= \frac{\text{J} \cos \alpha}{a^2 + b^2} = \frac{\text{J} \times \dfrac{a}{\sqrt{a^2 + b^2}}}{a^2 + b^2}$$
$$= \frac{a}{(a^2 + b^2)^{\frac{3}{2}}} \times \text{J candle-feet}$$

If the source of light J be that of an arc lamp whose polar curve of light intensities is known, the horizontal illumination of the surface to be illuminated can be calculated for the various values of α by multiplying the value of $\cos^3 \alpha$ by the corresponding value of J and dividing by the (height of the lamp)^2.

TABLE XIV.

a.	cos a.	tan a.	$\cos^3 a$.
0°	1	0	1
5°	0·9962	0·0875	0·996
10°	0·9848	0·1763	0·956
15°	0·9654	0·2679	0·902
20°	0·9397	0·3640	0·832
25°	0·9063	0·4663	0·747
30°	0·8660	0·5774	0·650
35°	0·8192	0·7002	0·549
40°	0·7660	0·8391	0·448
45°	0·7071	1·0000	0·3535
50°	0·6428	1·1918	0·266
55°	0·5736	1·4281	0·189
60°	0·5000	1·7321	0·125
65°	0·4226	2·1445	0·076
70°	0·3420	2·7475	0·0425
75°	0·2588	3·7321	0·0173
80°	0·1736	5·6713	0·0052
85°	0·0872	11·43	0·0006
90°	0	∞	0

In Fig. 135 the characteristic polar curve of a D.C. arc lamp of the open type is given in English standard candles; and for $a = 35°$, the light intensity is 2180 candle-power. The value of $\cos^3 a$ for $a = 35°$ is 0·549. If the lamp is suspended, so that crater is 25 feet above the ground, we have for the horizontal ground illumination for $a = 35°$—

$$\text{Illumination} = \frac{0{\cdot}549 \times 2180}{25^2}$$
$$= 1{\cdot}92 \text{ candle-feet.}$$

Obtaining the values of the horizontal illumination for the different angles, and plotting these to any scale as ordinates, the curve in Fig. 135 is obtained. In Fig. 136, the polar and illumination curves of a D.C. flame arc lamp with inclined carbons are similarly plotted. The curve shown in Fig. 135 is plotted from $a = 0°$ to $a = 61{\cdot}2°$, and from it the degree of variation of the horizontal illumination may be obtained,

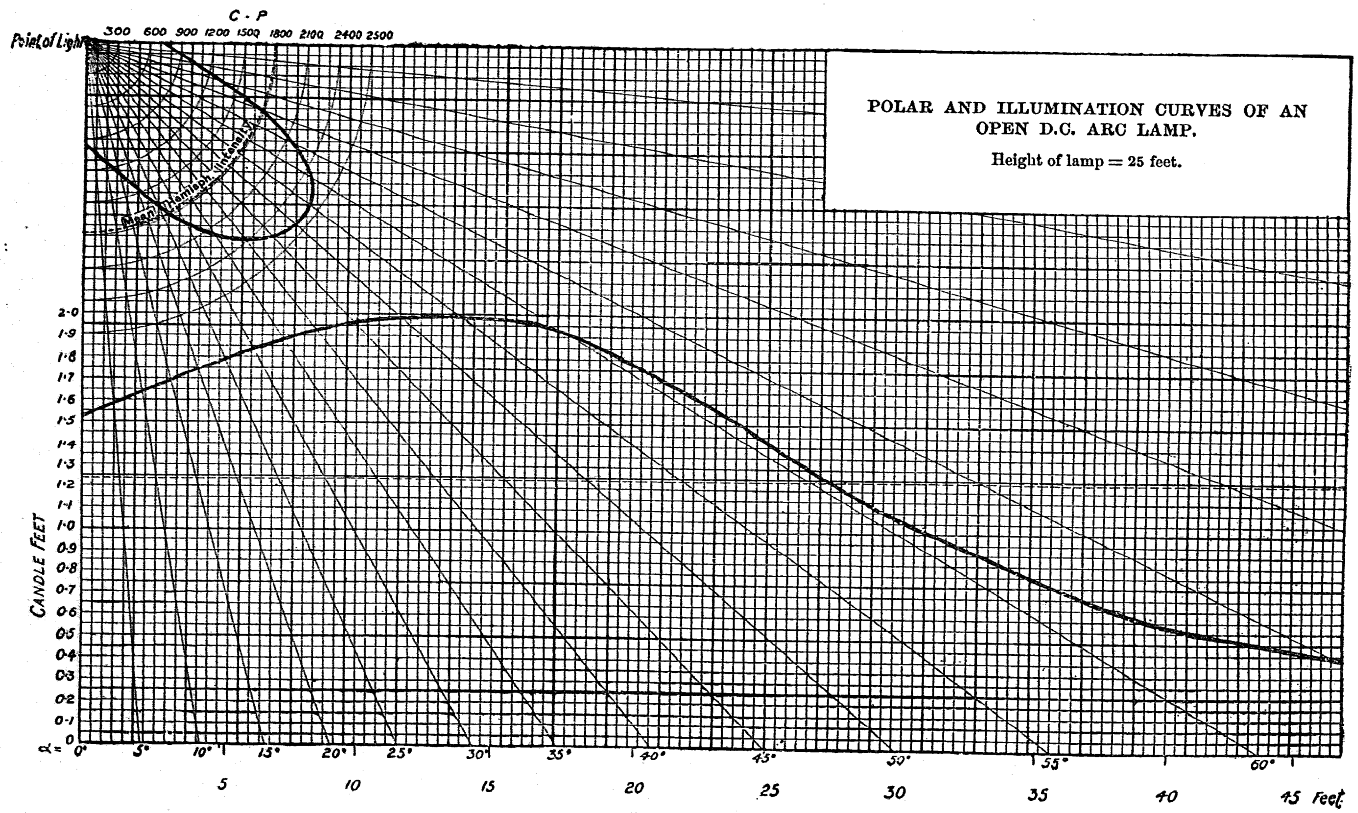

POLAR AND ILLUMINATION CURVES OF AN OPEN D.C. ARC LAMP.
Height of lamp = 25 feet.
C·P
Point of Light
300 600 900 1200 1500 1800 2100 2400 2500
Mean Hemisph. Intensity
CANDLE FEET
2·0 1·9 1·8 1·7 1·6 1·5 1·4 1·3 1·2 1·1 1·0 0·9 0·8 0·7 0·6 0·5 0·4 0·3 0·2 0·1 0
α = 0° 5° 10° 15° 20° 25° 30° 35° 40° 45° 50° 55° 60°
5 10 15 20 25 30 35 40 45 Feet

FIG. 135.

namely, the ratio of the difference between the maximum and minimum illumination to the *mean* illumination.

The mean horizontal illumination E_m depends upon the

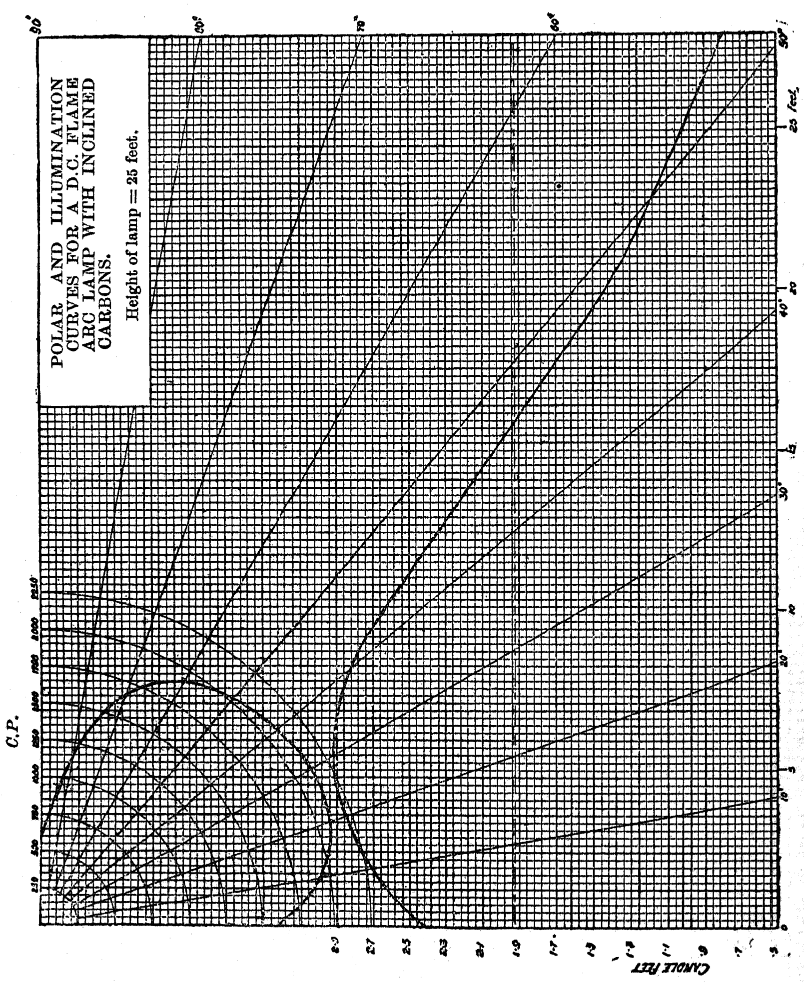


FIG. 136.

maximum solid angle of radiation ω upon the area of illuminated surface pertaining to the solid angle.

The value of the mean illumination for a given angle may

be obtained by regarding the curve of illumination as the boundary line of a rotating body, with the vertical through the point of the light as axis, and the illuminated surface as the base, and by transposing the cubical contents of this rotating body to a cylinder of equal base and volume.

The height of the cylinder gives the value of the required mean illumination E_m. For a solid angle $\omega = 122 \cdot 4°$ ($\alpha = 61 \cdot 2°$). This mean value is 1·24 candle-feet for the curve in Fig. 135.

In order to obtain the candle-power necessary for a given mean horizontal illumination, with a given source of light, it is necessary as the basis of the calculation to construct the horizontal illumination curve (corresponding to the characteristic polar curve) for a hemispherical light intensity of 1 standard candle-power at a height $a = 1$ foot. The values of the mean horizontal illumination for the different solid angles from 60° to 150° (in increments of 10°) are then obtained, and the products of these illumination values and the corresponding surfaces illuminated within the solid angles calculated. Each of these products gives the vertical component or useful part of the quantity of light radiated within the particular solid angle of distribution on to the horizontal surface illuminated.

If Φ is the total light distributed within the solid angle ω, and Φ_v the vertical component or useful part falling on the surface S (in square feet), E_m the mean horizontal illumination within the angle ω, then—

$$\Phi_v = E_m \, . \, S.$$

In the Photometric units, Appendix I., the *Lumen* is the unit of quantity of light, being that received on 1 square metre, possessing a mean illumination of 1 *Lux*.

As an example, Fig. 137 shows the construction of a *unit illumination curve* for the polar curve of an ordinary direct current arc lamp with globe, to be a basis for calculation, and in Table XV. the values of Φ_v calculated for different angles

ω are given. The curve applies also approximately to ordinary alternating current arc lamps.

UNIT ILLUMINATION CURVE

Mean hemispherical intensity = 1 c.p.
Height of lamp = 1 ft.
Polar curve.—Open Direct Current Arc Lamp with globe.

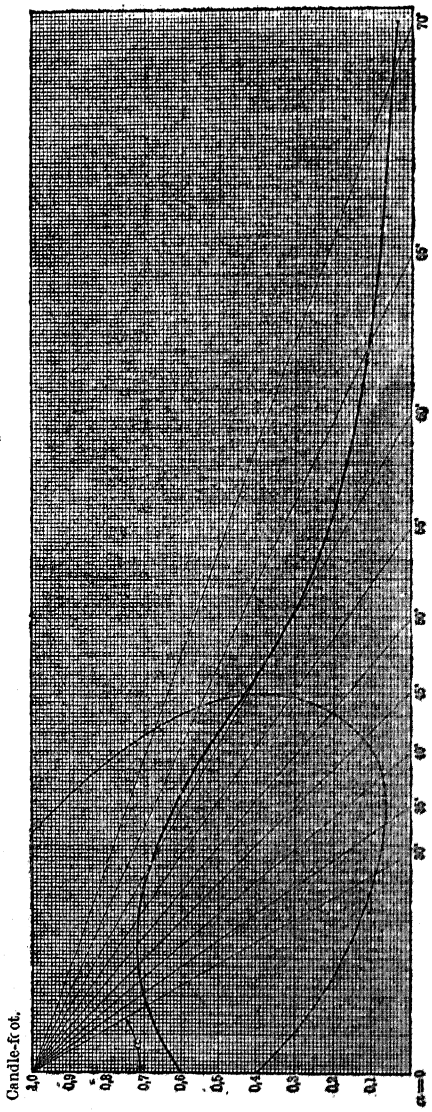


FIG. 137.

TABLE XV.

ω (= 2α).	Mean horizontal illumination E_m in candle-feet.	Vertical (useful) quantity of light Φ_v.	Difference.
60°	0·698	0·73	—
70°	0·682	1·058	0·32
80°	0·652	1·458	0·4
90°	0·607	1·91	0·460
100°	0·541	2·41	0·502
110°	0·457	2·924	0·514
120°	0·3448	3·447	0·523
130°	0·275	2·973	0·526
140°	0·177	4·4464	0·4746
150°	0·113	4·925	0·4790

The candle-power required for a given mean horizontal illumination for a given area is obtained by dividing the product of the area of surface to be illuminated and the mean illumination needed—that is, the total vertical component of the quantity of light necessary—by the vertical component or useful amount of light given by a similar source of light of unit hemispherical candle-power.

The quantity of light in a given solid angle is independent of the height of the source of light, because in the product E_mS the illumination E_m decreases with the square of the height, and the surface S increases with the square of the height. In Table XV. it will be seen that Φ_v increases with the angle of distribution, and without further data this angle in the majority of cases, cannot be definitely known.

Example of Lighting of a Public Square.—Let us assume that the surface is that of Fig. 138, of area 10,000 square yards (90,000 square feet), to be illuminated with direct current arc lamps, so that the mean horizontal illumination is about $\frac{1}{2}$ candle-foot. The necessary vertical component Φ_v will equal $\frac{1}{2} \times 90{,}000 = 45{,}000$.

We require to find the necessary number of lamps and the candle-power of the lamps provided with globes, which absorb,

say, about 25 per cent. of the light. We must decide at what height the lamps are to be suspended. For streets (including squares), poles are generally employed, so that the height a of the source of illumination is about 20 to 35 feet. For simplicity let us take 30 feet (10 yards in the figure) as the height.

We can reckon that per lamp a circular surface of diameter about three times the height of the lamp will provide us with good illumination. (For practical reasons, *e.g.* stoppage of traffic through use of too many poles, or the cost thereof, this diameter d is sometimes increased to four times the height, although the most uniform illumination is obtained with $d = 2a$.) Taking the height of the lamps as 30 feet, the diameter of circular surface per lamp equals 30 yards, and the surface about 700 square yards. Hence the number of lamps required for the square equals $\frac{10,000}{700} = 14$. It depends upon the shape of the surface to be illuminated whether this number of lamps can be suitably distributed, or whether a greater or smaller number of lamps should be employed. We shall choose thirteen lamps, distributed and numbered as in Fig. 138.

The maximum solid angle of distribution ω (see Fig. 137), of practical value, may be taken as 150° ($\alpha = 75°$) for ordinary direct current lamps for exterior lighting.

For a height $a = 30$ feet and the angle $\alpha = 75°$, the maximum circle of illumination e per lamp has a diameter $= 2 \times a \tan \alpha = 75$ yards. These circles, e, are drawn to scale in Fig. 138, and so also the circles for the side lamps with a smaller angle of distribution. Circle a, for example, corresponds to an angle ω of 90° ($\alpha = 45°$), circle b to an angle of 110° ($\alpha = 55°$), circle c to an angle of 130° ($\alpha = 65°$), and, lastly, circle d to an angle of 140° ($\alpha = 70°$).

From Table XV. can be taken for every proposed lamp the value of Φ_w, which corresponds to that circle of illumination which lies entirely within the surface to be illuminated. For

lamp No. 7 (Fig. 138) the approximate value of the vertical luminous flux Φ_v given by a source of light of a mean hemispherical intensity of 1 candle-power is 4·93, because the circle *e* corresponds to an angle of distribution of 150° and lies entirely within the surface to be illuminated. For each of the lamps 4, 5, 9, and 10 the value of Φ_v for 140° (circle *d*) is 4·45;

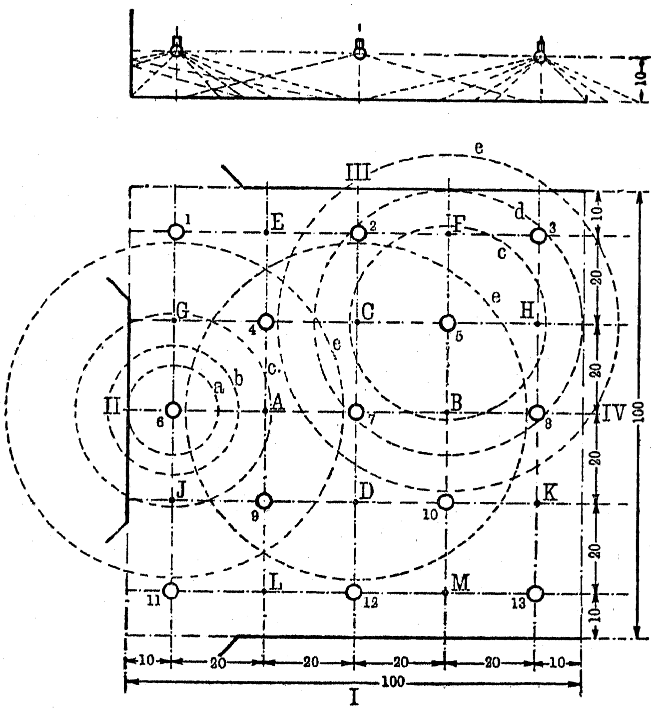


FIG. 138.

and to this must be added a fraction of the difference in Φ_v for 140° and 150°. According to Table XV. this difference is 0·48, and represents the vertical luminous flux falling on the surface lying between circles *c* and *d*. Of this surface only a portion for each of the lamps 4, 5, 9, and 10—about $\frac{9}{10}$—lies upon the ground to be illuminated; so that only $\frac{9}{10}$ of this difference 0·48,

i.e. $0{\cdot}9 \times 0{\cdot}48 = 0{\cdot}432$, need be added to the value $\Phi_v = 4{\cdot}45$ given above. The value of Φ_v for each of the lamps 4, 5, 9, and 10 for M.H.C.P. of 1 candle-power is equal to 4·882. The same method may be followed with the other lamps, except that here the value of Φ_v is chosen for a smaller angle of distribution from the table; *e.g.* for lamps 2, 6, 8, and 12 the value of the vertical useful quantity of light with an angle of 90° plus the correction for the surface lying between 90° and 150° in the illuminated square. It is not practicable to select the added correction as a fraction of the difference in Φ_v for 90° and 150°, but it is necessary to use one or two intermediate angles, viz. 110° to 130°. To the value Φ_v for 90° = 1·9 must be added the fractions of the values between 90° and 110°, 110° and 130°, and 130° and 150°. The added amounts depend, as already stated, upon the amount of the overlapping surface which falls within the surface to be illuminated. For the lamps in Fig. 138, Table XVI. gives the calculated results for a unit M.H.C.P.

For the surface to be illuminated the average value of the vertical useful quantity of light Φ_v per unit mean hemispherical candle-power amounts to 4·07, which value corresponds approximately to an angle of distribution of 130°. (For approximate calculation of the illumination of a public square of different dimensions than the one worked out, assumption of this angle of distribution, or rather the value of the useful quantity of light Φ_v corresponding to this angle, gives a sufficiently exact result for ordinary direct and alternating current arc lamps.)

For the surface under consideration we said that the total vertical luminous flux Φ_v required for a mean illumination E_m of $\frac{1}{2}$ candle-foot was $E_m \times S = \frac{1}{2} \times 90{,}000 = 45{,}000$. This amount divided by the mean value $\Phi_v = 4{\cdot}07$ for a unit M.H.C.P. and the number of lamps, viz. thirteen, gives the necessary mean hemispherical light intensity per lamp.

$$\text{M.H.C.P. per lamp} = \frac{45{,}000}{4{\cdot}07 \times 13} = 850$$

TABLE XVI.

Lamp No.	Angle of distribution of circle lying wholly on illuminated surface ω.	Φ_v per 1 M.H.C.P.	Fractions of the differences in Φ_v falling between.				Sum of values of Φ_v per lamp.	Average value of Φ_v.
			90° and 110°.	110° and 130°.	130° and 150°.	140° and 150°.		
7	150°	4·93	—	—	—	—	4·93	4·07 for a mean hemi-spherical intensity of 1 c.p.
4	140°	4·45	—	—	—	0·43	4·48	
5	140°	4·45	—	—	—	0·43	4·48	
9	140°	4·45	—	—	—	0·43	4·48	
10	140°	4·45	—	—	—	0·43	4·48	
2	90°	1·91	0·88	0·72	0·64	—	4·15	
6	90°	1·91	0·88	0·72	0·64	—	4·15	
8	90°	1·91	0·88	0·72	0·64	—	4·15	
12	90°	1·91	0·88	0·72	0·64	—	4·15	
1	90°	1·91	0·64	0·45	0·35	—	3·35	
3	90°	1·91	0·64	0·45	0·35	—	3·35	
11	90°	1·91	0·64	0·45	0·35	—	3·35	
13	90°	1·91	0·64	0·45	0·35	—	3·35	

From curve I. in Fig. 122, after allowing for loss of light in the globe, the required lamp current will be about 11 amperes (direct current).

The actual illumination in candle feet at the different points A, B, C, etc., can be determined by the aid of the standard curve in Fig. 137, by adding the values of the illumination obtained for the particular angles subtended by the direct rays from the influencing lamps, with the point under consideration and multiplying the result by the hemispherical intensity of the lamps and dividing by the square of their height.

For example, point A is illuminated at an angle $\alpha = 65°$, by lamps 2, 4, 5, and 7.

The values of the illumination for this angle from the standard curve is 0·08 candle-foot. The illumination at A due to the four lamps in question, each of 850 M.H.C.P., and 30 ft. high, is—

$$= \frac{0{\cdot}08 \times 4 \times 850}{(30)^2} = 0{\cdot}3 \text{ candle-foot.}$$

The same illumination occurs at points B, C, and D. Point E is only illuminated by three lamps, the angle a being 65°, hence the illumination at this point will be—

$$= \frac{0{\cdot}08 \times 3 \times 850}{(30)^2} = 0{\cdot}23 \text{ candle-foot,}$$

which illumination applies also to the points F, G, H, J, K, L, and M.

The maximum illumination, as seen in Fig. 137, is near the base of each lamp, at about $4\frac{1}{2}$ yards therefrom, at an angle a approximately $= 25°$ ($b = a \tan a = 10 \tan 25 = 4{\cdot}5$).

A point $4\frac{1}{2}$ yards to the right of lamp No. 7 will also be influenced by lamps 8, 5, and 10. The value of a (calculated) for lamp 8 is 74°, for each of lamps 5 and 10, $a = 68°$. From standard curve, Fig. 137, we have, for—

Lamp	7	$a = 25°$	0·71	Candlefoot per 1 M.H.C.P. 1 foot high.
,,	8	$a = 74°$	0·03	
,,	5	$a = 68°$	0·05	
,,	10	$a = 68°$	0·05	
		Total	0·85	

$$\therefore \text{Maximum illumination} = \frac{0{\cdot}85 \times 850}{(30)^2} = 0{\cdot}8 \text{ candle-foot.}$$

The degree of variation of illumination for the central part of the square is—

$$\frac{E_{max.} - E_{min.}}{E_{mean}} = \frac{0{\cdot}8 - 0{\cdot}3}{0{\cdot}5} = \frac{0{\cdot}5}{0{\cdot}5} = 1$$

or 100 per cent.

Example of Lighting of an Interior.—In planning an interior installation the same method may be followed, except that the power of reflection of the walls must also be considered. Suppose a room 45 × 45 square feet, and 21 feet high,* has to

* In Figs. 138–140 all numbers standing for distances, lengths, and heights are for convenience expressed in yards only.

be illuminated by ordinary direct current arc lamps, so that at the height of a table there is mean illumination E_m of 4 candle-feet. The necessary luminous flux Φ_v must amount to $45 \times 45 \times 4 = 8100$. The arc, considering the size of the lamp, may be assumed to be 3 feet beneath the ceiling, so that its height, reckoned from the table, may be taken as 15 feet.

The diameter of the useful circle of illumination of each lamp may be suitably chosen, for interiors, as one and a half to twice this height, *i.e.* $22\frac{1}{2}$ to 30 feet. From the area $45 \times 45 = 2025$ square feet, and from the useful circular areas controlled by a lamp, the necessary number of lamps is found to be three to five. Three lamps, however, in a square room, distribute the light badly, hence four, or, better, five, are chosen, which may be arranged as in Fig. 139. By drawing the illuminated circles belonging to the different angles of distribution, as shown in Fig. 138, for a height of 15 feet, and by proceeding as in the former case, then the mean vertical useful light, Φ_v, per hemispherical candle-power is 2·79, disregarding the gain by reflection from the walls. Assuming that 40 per cent. (see Table XIX.) represents the power of reflection of pure white walls, and that two-thirds of them is occupied by windows, etc., then about a quarter of the light falling upon the walls may be utilized for the room illumination and a corresponding addition must be made to the above calculated amount.

This additional amount cannot be calculated exactly because, apart from various degrees of absorption, rough surfaces do not reflect the light as do smooth surfaces according to the law of "the angle of reflection equal to the angle of incidence," the light being scattered in all possible directions. A portion of this light, therefore, only reaches the objects to be illuminated after repeated reflection, and sometimes it does not reach them at all. But since the surface to be illuminated does not absorb all the light which falls upon it, but partly reflects it, and partly receives it back from the reflection of walls and ceiling,

the reflection may be assumed for practical purposes to be that of a smooth surface in order to determine the additional value.

In Fig. 139 it will be seen that the circle for lamp 5 lying wholly on the plane to be illuminated, has an angle of distribution $\omega = 112°$, the next circle ($\omega = 130°$) lies partly on the

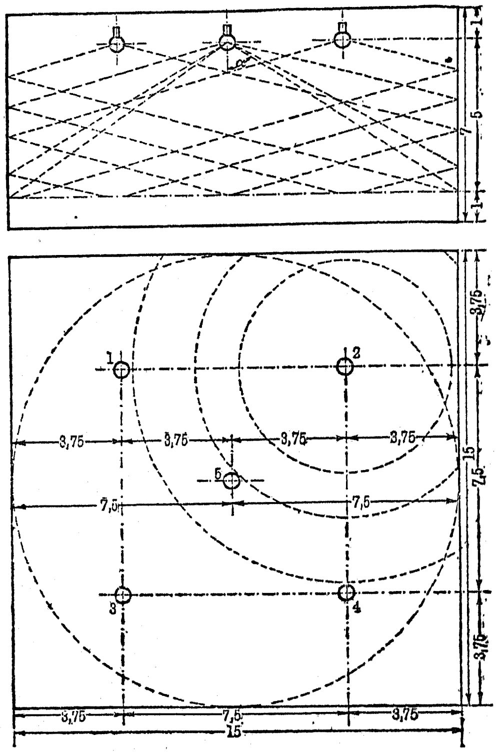


FIG. 139.

plane and partly on the walls. The maximum circle of distribution ($\omega = 150°$) lies wholly on the walls. For lamps 1, 2, 3, and 4 the smallest circle is for $\omega = 70°$. All other circles (not all drawn in Fig. 139), chosen in Table XVII. for these lamps, lie partly on the plane and partly on the walls from whence reflection takes place.

TABLE XVII.

Lamp No.	ω (=2α).	Φ_v.	Differences in Φ_v (fractions of).	Φ_v per lamp of 1 M.H.C.P.	Average value of Φ_v for 5 lamps per 1 M.H.C.P.	
1, 2, 3, and 4	70°	1·058	—			Average value with correction for reflection 2·79 + 0·57 = 3·36.
	70°–90°	—	0·610	2·671	Average value of $\frac{4 \times 2{\cdot}671 + 3{\cdot}294}{5} = 2{\cdot}79$ without reflections	
	90°–110°	—	0·545			
	110°–130°	—	0·392			
	130°–150°	—	0·066			
5	112°	3·03	—	3·294		
	112°–130°	—	0·264			
Corrections for reflection.						
1, 2, 3, and 4	70°–90°	—	0·059	0·612	Average value of $\frac{4 \times 0{\cdot}612 + 0{\cdot}406}{5} = 0{\cdot}57$	
	90°–110°	—	0·17			
	110°–130°	—	0·165			
	130°–150°	—	0·218			
5	112°–130°	—	0·169	0·406		
	130°–150°	—	0·237			

The additional correction for each lamp is found by taking the fractions of the differences in the values of Φ_v for the portions of surfaces lying between the circles of illumination which fall on the walls and reducing these to one-fourth part.

If the lamps are to be suspended so that their height above the table is only 10 feet, then for lamps 1, 2, 3, and 4 the circle of illumination corresponding to an angle of 90° falls wholly on the plane to be illuminated. The amount of the primary or direct light increases, whilst the amount of the secondary obtained by reflection of course decreases. The values for this height are given in Table XVIII.

TABLE XVIII.

Lamp No.	ω (= 2α).	Φ_v.	Differences in Φ_v (fractions of).	Φ_v per lamp of 1 M.H.C.P.	Average value of Φ_v. Without reflection.	Average value of Φ_v. With reflection.
1, 2, 3, and 4	90°	1·91	—	3·144	3·3	3·3 + 0·38 = 3·68
	90°–110°	—	0·507			
	110°–130°	—	0·467			
	130°–150°	—	0·26			
5	120°	3·447	—	3·897		
	120°–140°	—	0·45			
Corrections for reflection.						
1, 2, 3, and 4	90°–110°	—	0·127	0·444	Average value of $4 \times 0{\cdot}0444 + 0{\cdot}245 = 0{\cdot}38$	
	110°–130°	—	0·147			
	130°–150°	—	0·17			
5	120°–140°	—	0·125	0·245		
	140°–150°	—	0·12			

From the mean value of Φ_v and the required total amount of light $\Phi_v = 8100$, the light intensity per lamp for the case of five lamps at a height of 15 feet can be calculated.

A. 1. Excluding reflection from the walls $= \dfrac{8100}{2{\cdot}79 \times 5} = 580$ c.p.

2. Including " " $= \dfrac{8100}{3{\cdot}36 \times 5} = 480$ c.p.

For the same number of lamps at a height of 10 feet—

B. 1. Excluding reflection from the walls $= \dfrac{8100}{3{\cdot}3 \times 5} = 490$ c.p.

2. Including " " $= \dfrac{8100}{3{\cdot}68 \times 5} = 440$ c.p.

From curve I., Fig. 122, for a height of 15 feet direct current lamps of 8½ amps., and for a height of 10 feet direct current lamps of 8 amps. capacity would then be necessary.

Of course the smaller height requires a lesser consumption of energy, but the degree of variation in illumination is greater; moreover, there are practical reasons in particular cases which determine the minimum height at which lamps shall be placed.

In the former case, A, the gain of light from the walls amounts, according to our assumption, to about 16 per cent.; in the latter case, B, to 10 per cent., *i.e.* the smaller the angle of distribution within which the illuminated plane obtains primary or direct light, or the higher the lamp is mounted, the greater is the influence of the walls upon the illumination. In most cases the gain of light may be greater than is here assumed, and the illumination with the lamp considered will then be somewhat higher than the value used as the basis of the calculation.

With a given mean illumination and with indirect lighting, it is more difficult to calculate the required lamp current owing to the inexact determination of the amounts of the reflections. It must be pointed out that in the first place the ceiling can only be considered as a suitable reflector in rooms of 12 to 15 feet height, and even though the ceiling be painted often, about 40 to 50 per cent. of the light is only reflected. With higher or dirty ceilings it is better to attach enamelled reflectors to the lamp itself. These have been shown by experience to reflect 50 to 60 per cent. of the light, and they are easily cleaned. Approximately correct values may be obtained by supposing that the indirect light of a direct current lamp (Fig. 63) with a lower positive carbon is brought about by an image of the arc above the ceiling, and continuing the calculation in the same way as before, allowing for absorption by the ceiling. With a power of reflection of 50 per cent., double the calculated light intensity would be necessary.

Example of Lighting of an Interior with Inverted Arcs.—Suppose that a room 45 × 45 square feet and 15 feet high has to be illuminated by the indirect light of five lamps (Fig. 140), so that on a plane, the height of a table, there is a mean illumination of 4 candle-feet. The source of light is situated 3 feet below the ceiling, so that it may be considered as an image 3 feet above the ceiling. The example, as far as

dimensions go, is the same as the last. The calculation would then result in a candle-power per lamp equal to about double that given in previous example, A. 2 (p. 152), *i.e.* $480 \times 2 = 960$ c.p.* The arc of the lamp in question is open at the top, so that curve I., Fig. 122, gives the lamp current in

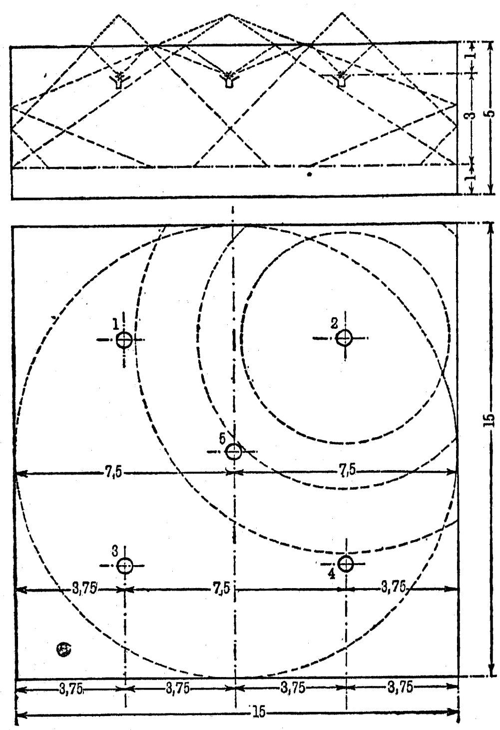
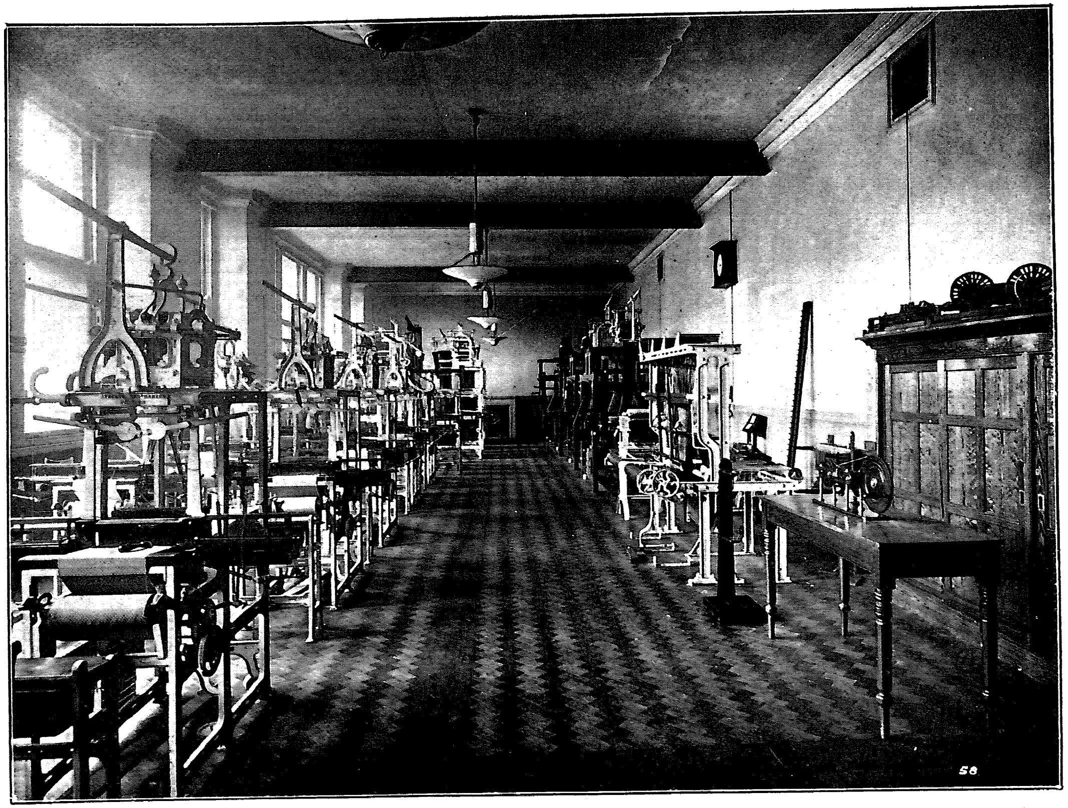


FIG. 140.

this case as 11 amps. In order to secure an equal illumination with the same lamp and the double reflection (the upper carbon

* This is not quite correct, as the standard or unit illumination curve for a lamp with globe has here been assumed. For inverted arcs, namely, lamps without globes, the unit illumination curve, and hence Φ per 1 c.p., could be obtained from the polar curve I., Fig. 123.

PLATE XVI.



Inverted Arc Lighting in the Pattern-Weaving Room, Textile Department, School of Technology, Manchester.

[*To face page* 155.

positive), about twice as many lamps would be required. In Tables XIX. and XX. some values of the reflecting powers of surfaces and approximate values of the mean horizontal illumination required for exterior and interior lighting are given.

TABLE XIX.

REFLECTION OF VARIOUS SURFACES (DR. SUMPNER).

	Percentage.
Yellow wall-paper	40
Blue ,, ...	25
Brown ,, ...	13
Yellow distempered wall (clean)	40
,, ,, ,, (dirty)	20

TABLE XX.

Necessary horizontal illumination E_m about 3 feet above the ground.	Candle-feet (about).
In spinning rooms	$1\frac{1}{4}$
,, weaving rooms producing light-coloured goods	$2-2\frac{1}{2}$
,, weaving rooms producing dark-coloured goods	$2\frac{1}{2}-3\frac{1}{2}$
,, works manufacturing machinery, smith's-shops, etc. ...	$2\frac{1}{2}$
,, mechanical workshops for instruments, etc.	$3\frac{1}{2}$
,, printing and typographic rooms	$3\frac{1}{2}-4\frac{1}{4}$
,, halls, according to size	$2\frac{1}{2}-3\frac{1}{2}$
,, drawing offices	$3\frac{1}{2}-4\frac{1}{4}$
,, commercial houses	$2\frac{1}{2}-3\frac{1}{2}$
,, shops	$2\frac{1}{2}-4\frac{1}{4}$
,, concert and banqueting halls	$3\frac{1}{2}-4\frac{1}{4}$
,, main streets and public squares	$\frac{1}{4}-\frac{1}{2}$
,, side streets	$\frac{1}{8}-\frac{1}{4}$

CHAPTER V

EXTERNAL CONNECTIONS (INSTALLATION) OF ARC LAMPS AND ACCESSORIES

I. EXTERNAL CONNECTIONS

GENERAL

GENERALLY in all types of arc lamps a resistance is used, which, according to the lamp construction, may be in the lamp circuit either continuously or only for the time during which the lamp is burning. The continuous connection is required by all shunt arc lamps, and also by series and differential arc lamps with a long arc, viz. enclosed and flame arc lamps. In series and differential arc lamps with a short arc (1 to 3 mm.), the resistance may be cut out in proportion as the lamp pressure (or the sum of the lamp pressures) increases with the consumption of the carbons, till the normal regulating pressure is reached. It is assumed in this case that the mains pressure amounts to one or more times the lamp pressure, plus the IR mains drop. The resistance is, therefore, made in several sections, and is provided with a special sliding contact. With a sufficiently great striking pull of the lamp and a sufficient cross-section of the leads, which can carry a momentary increase of the lamp current, the starting resistance may be omitted, in which latter case the mains pressure must be constant, and only the best carbons be used. For direct

current resistances only need be considered, whilst for alternating current both these and reactances (choke coils), are used. In the former case it is desirable to obtain the smallest possible dimensions of the resistance material used, but it must be unusually strong, so as to allow of an increase of temperature of several hundred degrees. It must, therefore, be mounted upon a fireproof base (soapstone, etc.), and have sufficient ventilation. Choke coils, on the other hand, waste much less power. Their winding is nearly always of cotton-covered copper wire, and the heating thereof must only be slight, owing to the cotton covering. It is desirable to mount the coil on a base which has no resonance.

The most suitable regulation of alternating current lamps is dependent on the shape of the current curve. This again is influenced according as choking coils, arc lamp transformers, or non-inductive resistances are used. The regulation of the lamps in the test rooms of works is therefore properly effected with their corresponding accessories.

Each circuit is generally protected against shorts, etc., by double-pole fusible cut-outs, which will fuse at three times the lamp current, and the minimum diameter of the leads is chosen accordingly. Every circuit is likewise provided with a special double-pole switch, and also, if several circuits are switched in or out with a common switch, as is often the case if the switching-in of distant circuits is effected by a common feeder from the Central Station.

The supply leads are connected to terminals fixed in the lamps in such a way, that with direct current, the positive main is connected to the positive cored carbon through the fuse and the switch. With series working the negative carbon is connected to the positive carbon of the next lamp, and so on. The resistance may be connected with any desired lamp or with the row of lamps in series. With alternating current a particular order of connection of the lamps with regard to the carbons is unnecessary.

The ohmic value R of the resistance may be determined by the formula—

$$R = \frac{E - (e_1 + e_2 + \ldots + e_m)}{I}$$

where. E = supply pressure, $e_1, e_2, \ldots$ = lamp pressures, e_m = pressure drop in leads, I = lamp current.

In general, the value of the resistance is only determined approximately, but is made capable of variation, and is adjusted with the help of a voltmeter and an ammeter until the heated lamps maintain the correct and constant electrical value, for which they have been previously adjusted in the works' test-room. With inductive resistances (choke coils), which are only used for alternating current, the resistance of the winding is only of secondary importance. With direct current, inductive resistances cause the arc to be struck more quickly, but are little used owing to their cost. It usually suffices to determine the reactance pressure to be created by the choke coil with the particular lamp current passing through it, whilst the exact adjustment is only made where the lamp is connected in circuit, as in the case of the non-inductive resistance above. The necessary reactance pressure e_s of the choking coil is calculated by the formula—

$$e_s = \sqrt{E^2 - (e_1 + e_2 \ldots e_m)^2}$$

or more accurately—

$$e_s = \sqrt{E^2 - (e_1 + e_2 \ldots + e_m + IR)^2}$$

in which IR is the ohmic drop of the choke coil and e_m the pressure drop in the leads. The terminal pressure e of the choking coil is then—

$$e = \sqrt{e_s^2 + (IR)^2}$$

or—

$$e_s^2 = E^2 - (e_1 + e_2 \ldots + e_m + IR)^2$$
$$e_s^2 = e^2 - (IR)^2$$
$$e^2 - (IR)^2 = E^2 - (e_1 + e_2 + \ldots + e_m + IR)^2$$
$$e = \sqrt{E^2 - (IR)^2 - (e_1 + e_2 \ldots + e \ + IR)^2}$$

The choking-coil terminal pressure may be easily obtained graphically as in Fig. 141, in which E is the mains pressure to a given scale of volts. On E a semi-circle is drawn with half E as radius. Then the sum Σe of the lamp pressures e_1, e_2, etc.,

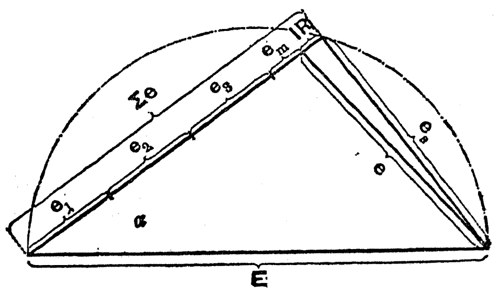


FIG. 141.

plus the mains drop (and, if known, the ohmic drop in the choking coil) is drawn to the same scale of volts as E in the diagram by describing an arc with centre on the extreme end of E and radius Σe and joining up the point of intersection with semi-circle to the extreme end chosen.

The reactance pressure e_s of the choking coil is E times the sine of the angle by which the lamp current is out of phase with the mains pressure. As the lamp current I (flame arc lamps excepted) is in the same phase with the lamp pressure the consumption of energy in the lamp circuit equals—

$$I\,(e_1 + e_2 \ldots e_m + IR) = I\,.\,E \cos \alpha$$

EXTERNAL CONNECTIONS AND ADJUSTMENT OF DIRECT CURRENT LAMPS.

Without accessory apparatus, series type of lamps, as already mentioned, are only suitable for single or parallel connection, as shown in Fig. 142. With the mains pressure, 110 to 220 volts usually employed, the only series lamps which need be considered are enclosed lamps with a P.D. across the arc of 70 to 80 or 130 to 150 volts.

A voltmeter placed across the terminals suffices to adjust the lamp resistance. The latter must be so adjusted that the lamp burns with the correct P.D. across the arc in the normal condition. As the burning away of the carbons in enclosed arc lamps is exceedingly slow, it often happens that the normal regulation is only reached after some hours.

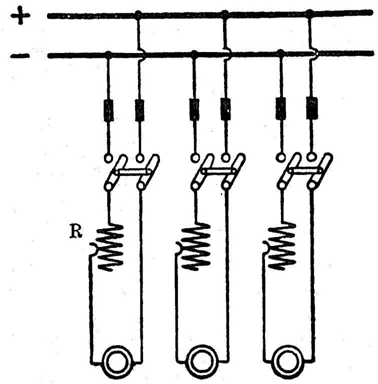


FIG. 142.

To save time, the inner globe is removed (if practicable) until the resistance is correctly adjusted. By this means the carbons burn away more quickly and the electrical conditions of the lamp adjust themselves in a shorter time. The correct connection of the terminals to the mains for direct current is checked by switching off the lamp and observing the carbon points: that carbon which glows longest is obviously connected with the positive pole of the supply, and with enclosed lamps must always be the upper carbon. If this is not found to be the case, the connections must be reversed.

EXTERNAL CONNECTIONS AND ADJUSTMENT OF SHUNT ARC LAMPS.

Shunt lamps are adopted for both multiple and series connection. In order to obtain a steady light the supply pressure must be considerably greater than the pressure required by each lamp. This difference, about 25 to 35 per cent. of the mains pressure, is absorbed by the mains drop and the separate lamp resistances.

With 110 to 220 volts, two or four direct current lamps can

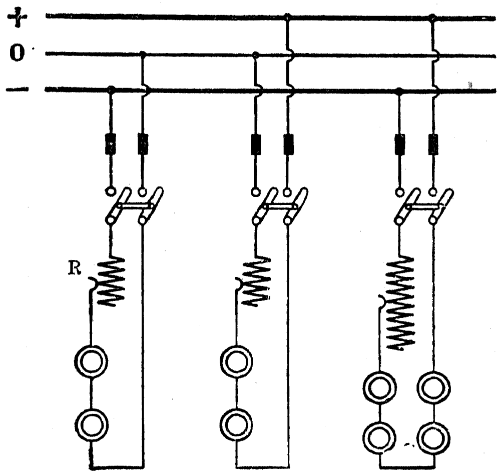


FIG. 143.

be connected with a P.D. across the arc of 40 volts. With 220 volts, five direct current lamps may also be connected with 35 volts P.D. across the arc; and three or six alternating current lamps in series with 30 volts P.D. across the arc, for 110 and 220 volts respectively. If the number of lamps to be installed is greater than the number possible to be put in series for the given supply pressure they can be divided into groups connected in parallel, each group consisting of a possible

number of lamps and a resistance in series as in Fig. 143. The current with which the lamps burn depends upon the value of the resistance. In order to fix the latter, an ammeter should be inserted in each lamp circuit in turn, and the resistance increased or decreased until the ammeter indicates the required lamp current. This should be done when the lamps are heated to their maximum, which is generally reached, at the latest, after burning for an hour and a half.

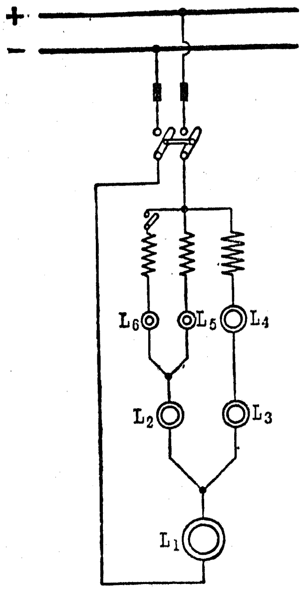


FIG. 144.

By the use of a regulating resistance (with a lever handle) the current and the light intensity can be regulated at any time within the limits of 25 per cent. above or below. The permanently connected portion of the resistance is then adjusted for the maximum current. Combinations of lamps such as shown in Fig. 144 may be employed. It must be pointed out that in this case the resistances must be connected to the individual branches, and the desired current in these must be correspondingly regulated.

The sum of the currents in two adjacent branches will be the current passing through the lamp connected to the junction of these branches, and so on. For instance, lamp L_2 burns with the sum of the lamp currents L_5 and L_6, which may themselves be unequal. L_5 or L_6 may be switched off if necessary, provided that L_2 burns correspondingly thin carbons.

EXTERNAL CONNECTIONS AND ADJUSTMENT OF DIFFERENTIAL ARC LAMPS.

Differential lamps, like shunt lamps, may be connected in single, multiple, in multiple series, or in series.

The regulation of the electrical conditions of the arc is more exact, since both the P.D. across the arc and the lamp current influence the mechanism, and the unsteadiness of light, due to varying mains pressure, is less than in shunt lamps. A disadvantage of this lamp, as contrasted with the shunt, is that the light intensity cannot be obtained by altering the resistance only, as in the shunt lamp, but the ampere-turns in the regulating magnets must be also adjusted. The alteration of the turns is effected by providing tappings to particular portions of the winding. These tappings make it possible to put in or cut out a number of turns. Further, an adjustable resistance may be connected in parallel with the series magnet so that only a part of the lamp current passes through its turns. The alteration of the electrical conditions of one lamp, by the above adjustment, influences also the regulation of the remaining lamps in series. An adjustment of the lamps (already installed) for another current is therefore generally not practicable without auxiliary apparatus. A voltmeter placed across the terminals of direct current differential lamps is used to fix the resistance exactly, so that in a heated condition of the lamp, the latter burns with the correct P.D. across the arc. The lamp current will then be correct, assuming that with above adjustment the lamps have been regulated in the works for the desired pressure.

With alternating current a subsequent adjustment of the lamp cannot be avoided, because the wave form of the current influences both the most suitable arc length (*i.e.* the P.D.) and the attraction of the regulating magnets, assuming that the frequency of the current is the same as the one at which the

lamp was regulated by the makers. It is desirable to connect an ammeter in the lamp circuit when adjusting the reactance by means of the voltmeter across the lamp terminals.

If in lamps with an open arc and untreated carbons the light is of a violet hue (too long an arc), or the light is too little (too short an arc), the reactance must be increased or decreased accordingly. If the ammeter shows too great a deviation from the desired current, readjustment is necessary. This should only be done by a skilled hand.

In adjusting alternating current flame arc lamps of both varieties, only measuring instruments independent of wave form and frequency of the current must be used.

II. ACCESSORIES FOR EXTERNAL CONNECTIONS.

The most necessary accessories are the frequently mentioned resistances; of the others, we have regulating resistances with

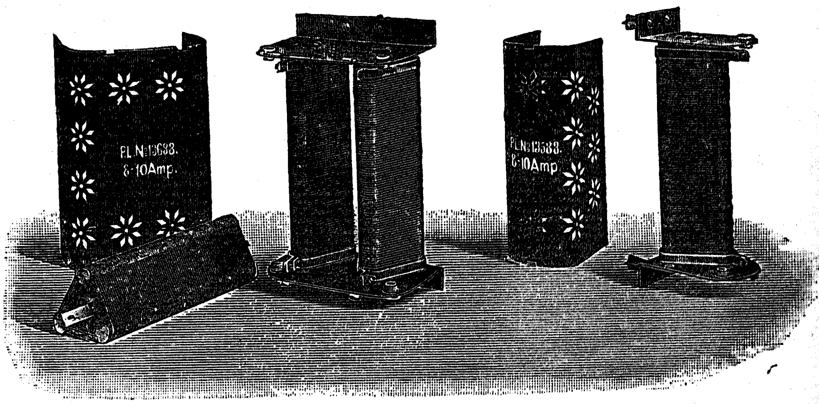


Fig. 145.

lever, automatic resistances, choking coils, transformers, and automatic appliances, which prevent the extinction of other lamps in series should one go out.

Lamp resistances usually consist of 60 to 80 feet of Eureka wire, 1 to 2·5 mm. diameter, for loads of 3 to 15 amperes. These wires are wound on solid, bare porcelain reels or porcelain insulators joined together. Adjustable metal collars act as contacts. According to the place of the mounting, they are provided with a perforated or rainproof covering (Figs. 145 and 146).

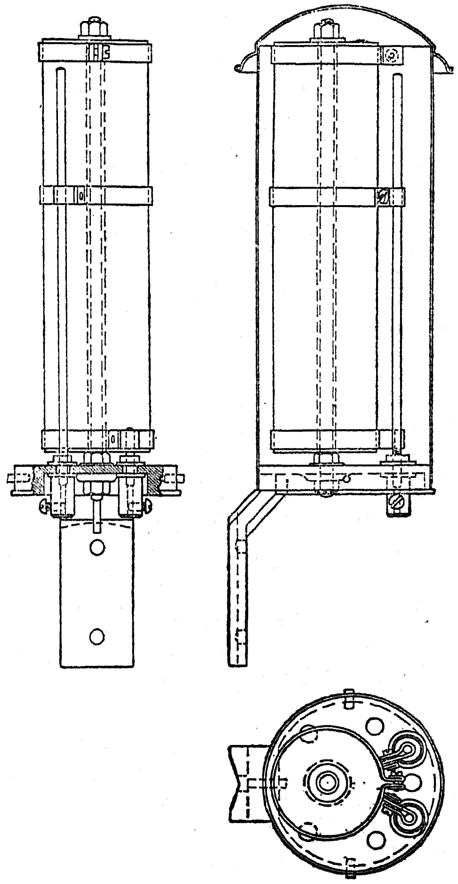


FIG. 146.

A *starting resistance* with a lever handle is shown in Fig. 147. It consists of a number of spirals of Eureka wire fixed to and insulated from a cast-iron base with cover and suitable contacts connected to points of the spirals. The lever (the handle of which can be seen in Fig. 147), moved slowly over the contacts in the direction of the arrow, cuts out these spirals. Figs. 148, 149, and 150 show the connections of direct current differential arc lamps for 110 to 220 volts and the use of this starter.

Automatic starting resistances (Fig. 151) need only be

considered in those cases in which hand-manipulated starters

Fig. 147.

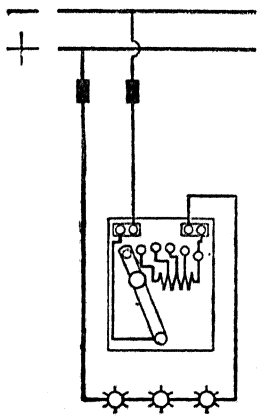


Fig. 148.

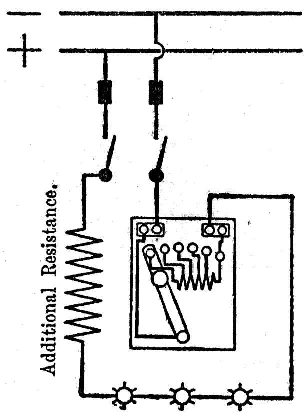


Fig. 149.

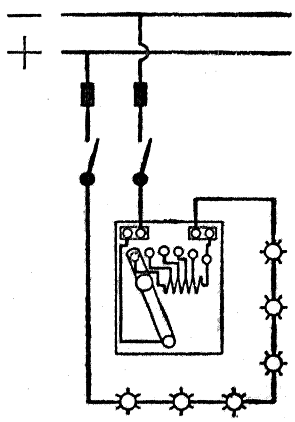


Fig. 150.

are not suitable, either owing to lack of time or to the

unreliability of the persons to whom the switching on of the lamps is entrusted.

They usually consist of a solenoid through which the lamp current passes. At one end of the iron core is a

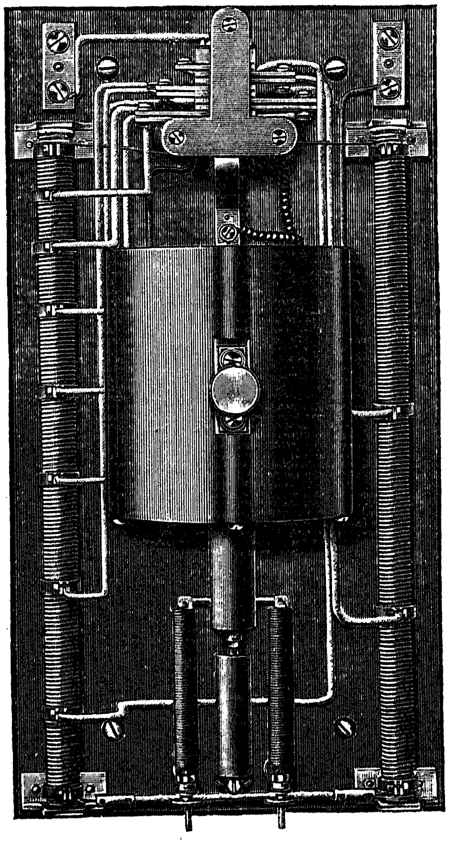


FIG. 151.

sliding contact which slides over a number of segments. At the other end is a spiral spring and a dashpot which counter-balance the attraction of the solenoid and form a brake to the movement. The segments of the contact surface

are connected with definite points of the resistance, as shown in the scheme of connections in Fig. 152.

Fig. 153 shows a *choking coil* consisting of a rectangular iron core built up of stampings with the four sides bolted together. Two limbs are wound with insulated copper wire,

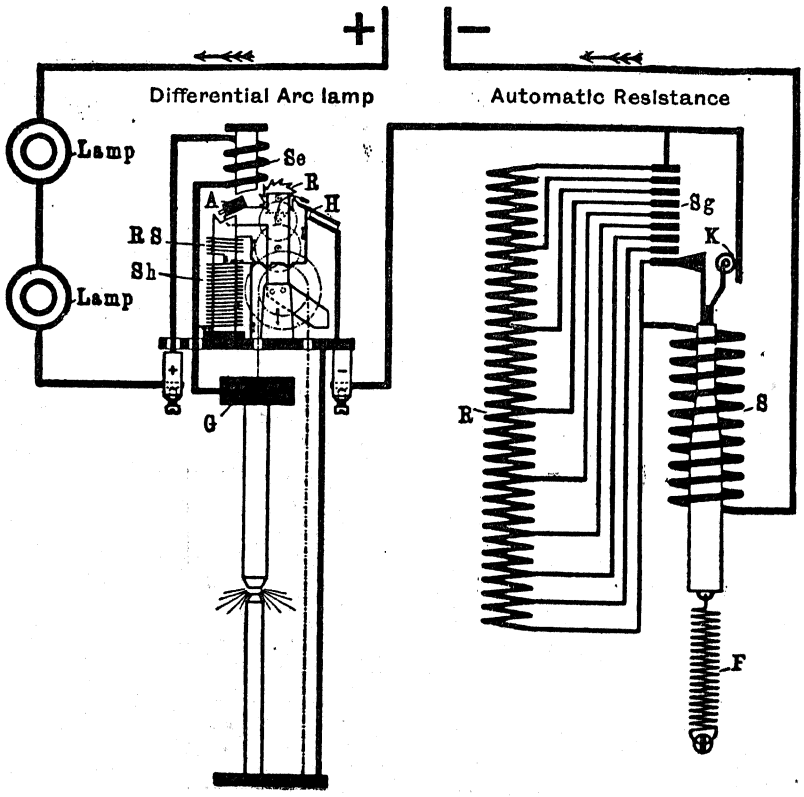


Fig. 152.

and the whole is enclosed in a protecting cover. The four parts can be bolted so that an air space may be introduced between the cross-pieces and the wound limbs, in order to regulate the reactance pressure (*i.e.* the impedance of the choke coil) with a given magnetizing current (lamp current).

Fig. 154 shows an A.E.G. *arc lamp transformer;* for pressures up to 220 volts these small transformers are nearly always constructed as auto-transformers or economy coils, in which both primary and secondary currents pass through the lamp. If I is the lamp current, i_1 the primary current, and i_2 the secondary current of the economizer

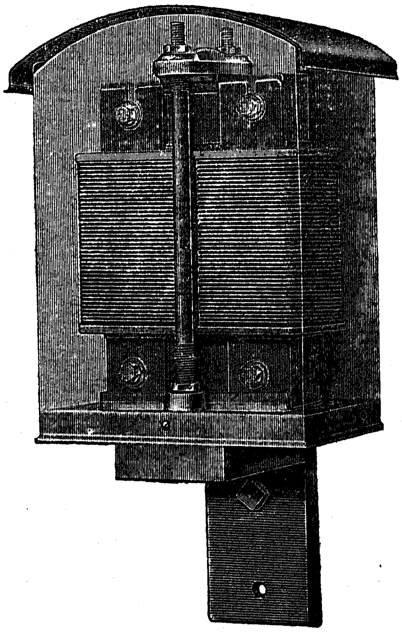


FIG. 153.

(Figs. 155 to 157), then, neglecting the magnetizing current—

$$I = i_1 + i_2$$

If e is the secondary pressure of the transformer, then the supply to the lamp circuit is $Ie = (i_1 + i_2)e$; but the load of the transformer itself is only $i_2e = Ie - i_1e$, that is, the load on the transformer may be smaller than that necessary for the lamp

circuit by the product of the primary current and the secondary pressure. If E is the supply pressure, then the primary current

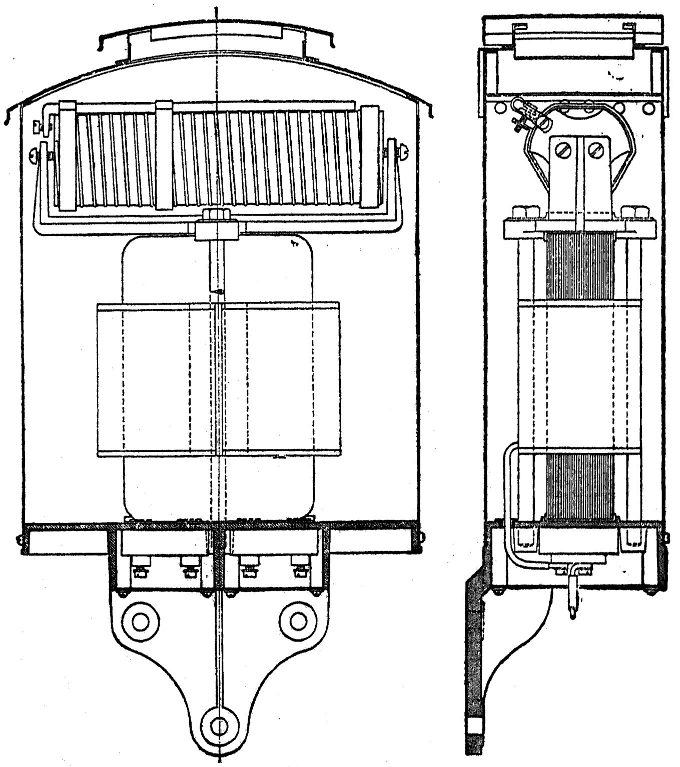


FIG. 154.

(i_1) is given by considering the primary and secondary watts of the transformer.

We have—

$$i_1(E - e) = i_2 e$$

hence—

$$i_1(E - e) = (I - i_1)e$$

$$i_1 E = Ie$$

$$i_1 = \frac{Ie}{E}$$

in which formula, allowing for the necessary steadying resistance, e must be taken about 25 per cent. higher than the lamp itself requires at the terminals.

The steadying resistance is usually connected in the primary circuit in order to diminish still more the transformer load, so that, in fact, e is then only greater than the lamp pressure by the amount of the drop in the leads between the transformer and the lamp. This holds good with single lamps or lamps

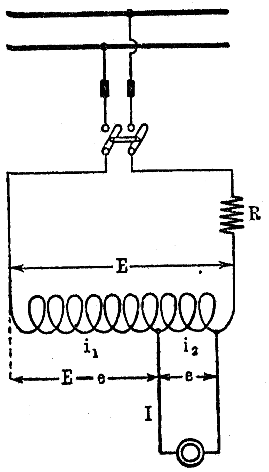


FIG. 155.

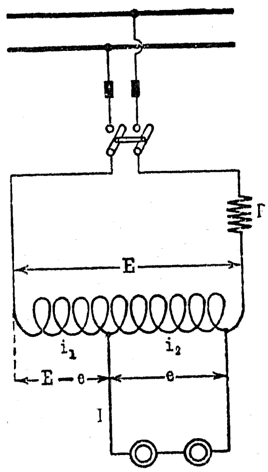


FIG. 156.

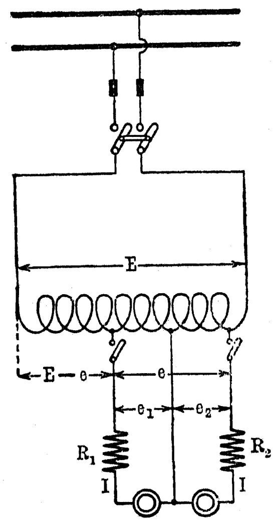


FIG. 157.

burning in series, assuming in the latter case that the lamps always burn together (see connections in Figs. 155 and 156). With the connections as in Fig. 157, where one lamp may be switched out, the steadying resistance must be placed in the lamp circuits.

The *automatic substitutional appliance* is used as desired with arc lamps connected in series. Its purpose is to ensure the continuous burning of lamps connected in series, should one of them be extinguished. It is also intended to prevent a high

pressure at the terminals of the individual lamps which would unduly heat the lamps or fuse the winding of the shunt magnet. This appliance is nearly always used with direct current pressures above 220 volts, and alternating current above 130 volts. Beneath these limits the use of the appliance depends more or less upon the construction of the lamp (viz. upon the watts

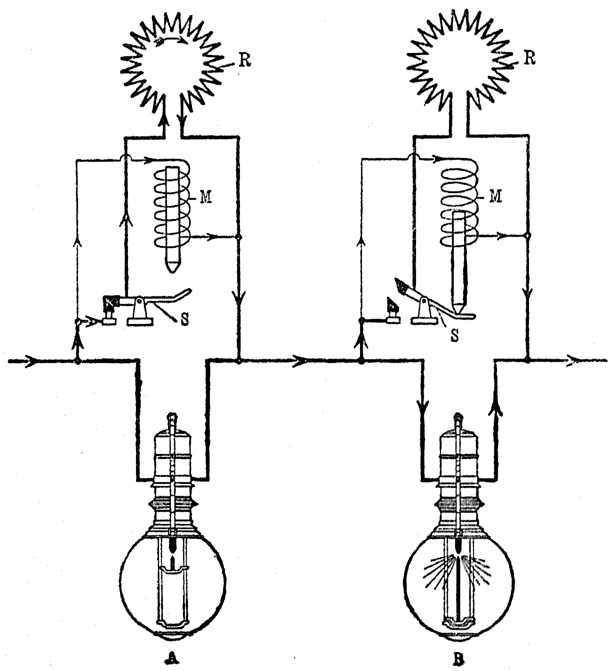


Fig. 158.

consumed by the shunt winding, etc.), and upon the degree of safety desired with a given installation. In railway stations, for example, such an appliance is generally employed. It usually comprises an *automatic switch* and a *compensating resistance.* The latter is switched into the lamp circuit instead of the arc resistance, when a lamp is extinguished.

The automatic working of the switch S may be so operated (Fig. 158) by a special electro-magnet, M, excited by the lamp pressure, that with an unduly rising lamp pressure (as when the feed has ceased) the magnet draws up the iron core and holds it so long as the carbon points do not touch for striking the arc.

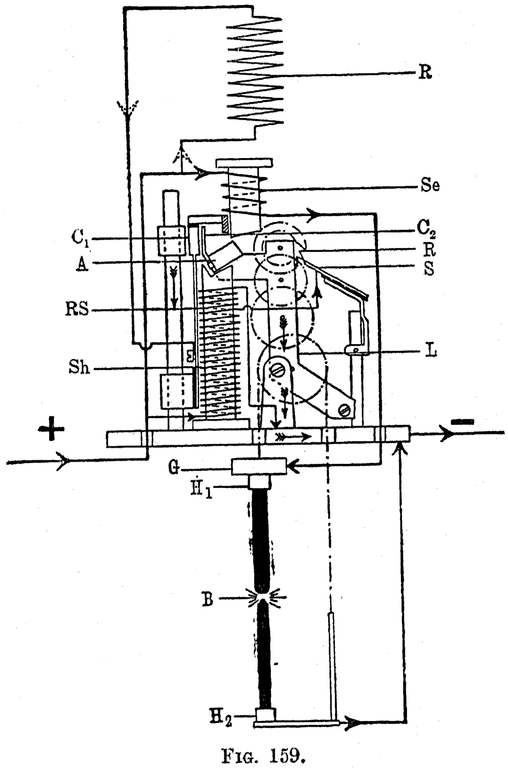


FIG. 159.

The switch may close by gravity or springs and thereby switch in the compensating or substitutional resistance. In Fig. 158 at A the lamp is supposed to be extinguished and the resistance R switched on, whilst at B the lamp is burning and the resistance R switched off. In most cases the automatic switch is

operated by the lamp mechanism and the substitutional resistance is fixed in the lamp, as is shown in the A.E.G. direct current differential arc lamp (Fig. 159). The current flows as follows :—

(A) When a lamp is burning: The main current flows from the positive terminal through the series magnet coil Se to the upper carbon holder H_1, to the arc B, the lower carbon holder H_2, and to the negative terminal. The shunt current flows from the positive terminal to the shunt magnet winding Sh, the detent S, the escapement R, to the base plate and negative terminal.

(B) When the lamp is extinguished, owing to used-up carbons or any obstructions which prevent the separation of the carbons: The armature is drawn down by the shunt magnet Sh further than is necessary for the release of the escapement R from the detent S. The contact pieces C_1 and C_2 then touch and remain in contact, so that the substitutional resistance R is switched in. The main current then flows from positive terminal through the resistance R, through the contacts C_1 and C_2, back to the base plate and negative terminal. The shunt current flows from positive terminal to the magnet RS and back to the base plate and negative terminal.

The shunt magnet is continuously excited and maintains the contact between C_1 and C_2 so long as the remaining mechanism of the lamp does not perform its functions. If the latter works, *i.e.* if the carbons touch, the shunt magnet is short-circuited, and consequently becomes void of current, whilst the series magnet is strongly excited and draws the armature up and the contact C_2 away from the contact surface C_1.

With alternating current arc lamps a similar apparatus may be used, or choking coils may be connected in parallel with the lamps, which is the more usual method (Fig. 160). These choke coils, called *compensating coils*, absorb continuously a few watts (about 15 per coil), but have the great advantage of absolute

safety, owing to the elimination of any contact device. In contrast to the ordinary choke coils mentioned on page 168

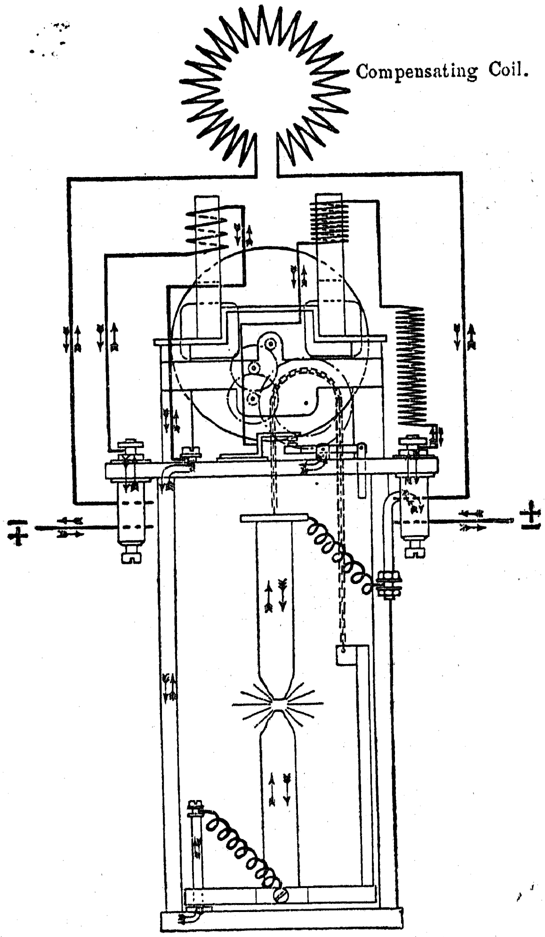


FIG. 160.

these choke coils have a constant well-closed magnetic circuit. They are so wound that with the normal lamp pressure they take little magnetizing current, and the iron is highly

saturated. If for any reason the feed of a lamp ceases, the lamp pressure will immediately rise and a large part of the

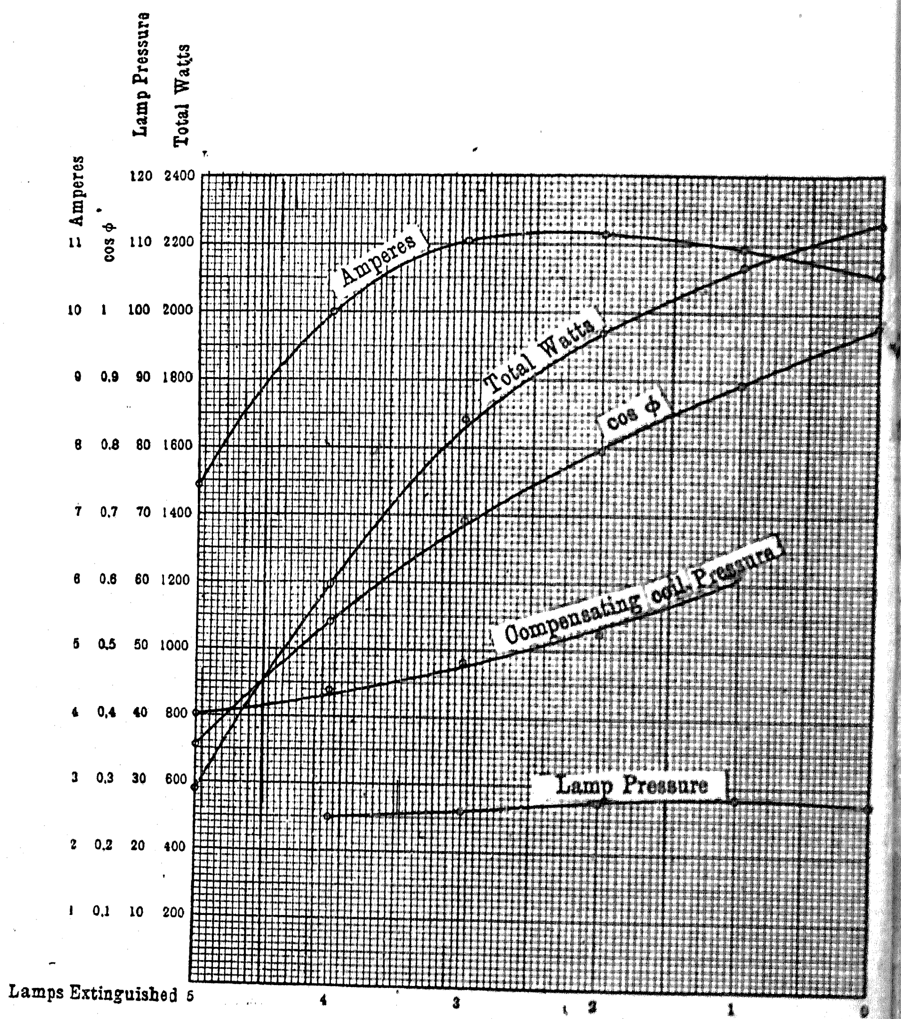


FIG. 161.

main current will flow through these safety coils, until, finally, the arc is extinguished and the whole of the current passes

through the coil. In Fig. 161 is shown the variation of current, lamp pressure, consumption of watts, power factor, etc., for six alternating current lamps in series, with a supply pressure of 220 volts, being extinguished consecutively and replaced by their compensating coils. If all the lamps are burning, the power factor is, in spite of the shunted choke coils, about 1 ($\cos \Phi = 0{\cdot}98$). If one lamp goes out the pressure at the terminals of the safety coil now called into operation increases to about double the lamp pressure. Since the compensating coil pressures are added vectorially, the current and lamp pressures of the remaining lamps alter but little, in spite of this increased pressure per coil, whilst the power factor amounts to 0·9. When a second lamp goes out the total impedance pressure of the compensating coils falls too, although the current increases. The cause of this is the alteration of the wave form of the current owing to the switching in of these reactances. This alteration in wave form also occurs owing to the increased arc length which takes place, although the lamp pressure remains almost the same. It is only when more than three lamps are extinguished that the variation of current and pressure becomes so great that the remaining lamps do not burn satisfactorily. This is not important in practice, since when one lamp has gone out remedial steps are taken.

An additional safety apparatus is the *minimum automatic cut-out*. This is used when the lamp is not provided with the above described compensating device. They are also used when the strength of the supply pressure would cause a burning out of the shunt windings of single lamps in the event of a single lamp going out and the circuit not being broken in time. Fig. 162 shows the construction of such a switch of the A.E.G. In this a magnet M, excited by the lamp current, draws up the armature A pivoted at O. The armature with normal lamp current holds the switch blade by means of a projecting piece N. If the feed ceases in the lamps, after the carbons have been

consumed, then the P.D. across the arc increases and the lamp current decreases, until, finally, the electro-magnet of the minimum cut-out lets the armature fall, so that the projection frees the switch blade. Under the influence of the springs F_1 and F_2 the switch is sprung out of the contacts G, and at the same time the circuit is broken. The protection given by this apparatus is, however, only conditional, since, for example, if the lamp pressure increases in one lamp only, the P.D. in the remaining lamps decreases with the lamp current (assuming

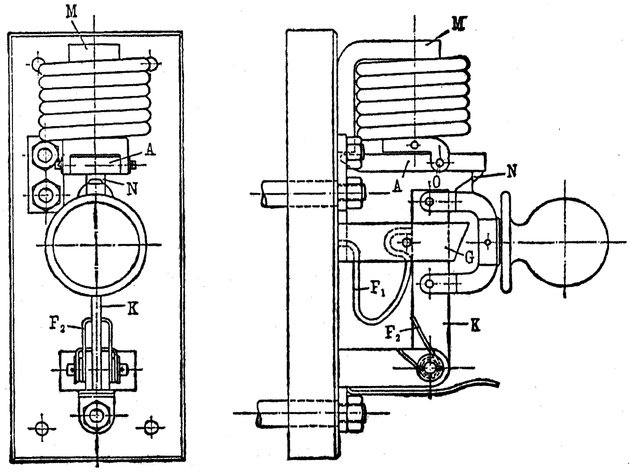


FIG. 162.

differential lamps). Under certain conditions the terminal pressure of one lamp may attain a value which is dangerous for the magnet winding, without the alteration of current being great enough to bring the minimum switch into operation and to break the circuit. Another disadvantage of this apparatus is the undesired breaking of the circuit if for any reason there is a temporarily large decrease in the supply pressure.

There still remains to be mentioned the *current indicator*. It is connected in the lamp circuit in those cases in which the

switching-in of the lamps is effected from a place at which it is not possible to see if the lamps are burning or not. Fig. 163 shows such an indicator. It consists of a solenoid, through

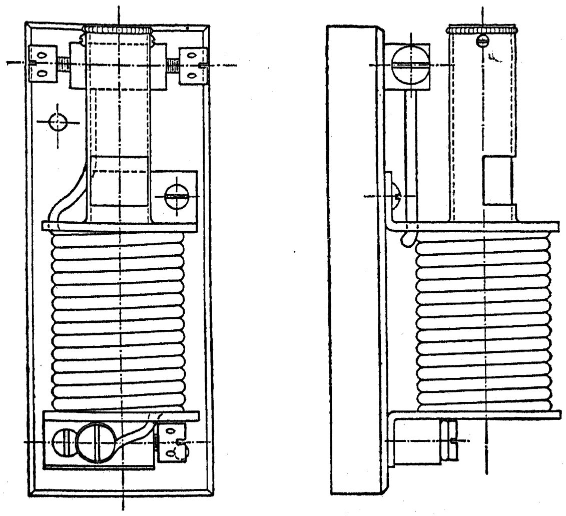


FIG. 163.

which the lamp current passes, which attracts an iron core with a mark on it. From the position of the iron core the operator can discern the presence of the correct lamp current.

APPENDIX I

Table of Photometric Quantities *

Quantities.			Base of British System of Units; Candle-foot-hour.		Base of International System of Units; Candle-metre-hour.	Formulæ.
Definition.	Nomenclature.	International symbol.	Definition of Unit.	Nomenclature.	Nomenclature.	
The luminous intensity of a point source of light	Luminous Intensity or Intensity	J	The light intensity of a standard candle in a horizontal direction	Candle † Candle-power C.P.	Candle ‡	
The light, emitted by a point source, illuminating a solid angle ω	Luminous Flux	Φ	The luminous flux radiated by the candle into a unit solid angle	Candle-lumen	Lumen (Lm)	$\Phi = J\omega$
The product of a luminous flux and its time of duration	Quantity of Light	Q	The unit flux lasting during unit time	Candle-hour	Lumen-hour	$Q = \Phi \, . \, T$ T = time in hours
The ratio of a luminous flux falling upon a plane surface to the area of the surface	Illumination	E	The illumination of a unit surface by unit flux, or (what is the same), the illumination of a plane surface placed normal to the flux at unit distance from the standard candle	Candle-foot	Lux (Lx) Candle-metre	$E = \frac{\Phi}{S}$ S = area in sq. ft. [Br.] S = area in sq. metres [Int.] $E = \frac{J}{R^2}$ R = distance in feet [Br.] R = distance in metres [Int]
The ratio of a luminous intensity of a bright plane surface measured normally to the area of the surface	Intrinsic Brightness or Brightness	h	The intrinsic brightness of a surface, unit area of which possesses a normal light intensity of unit candle-power	Candle-power per sq. foot (or sq. inch)	Candle per sq. metre (or sq. cm.)	$h = \frac{J}{S}$ S = area in sq. feet (or sq. inches) [Br.] S = area in sq. metres (or sq. cm.) [Int.]

* Founded on table by L. Weber.

† See page 120 for British unit.

‡ International unit not yet agreed upon, but meanwhile at a meeting of the International Lighting Commission held at Zurich, 18th–20th July, 1907, the following values were fixed, as the mean of results of British, German, and French measurements:—Harcourt unit = 1·095 Hefner-candles = 1·020 Carcel-candles.

APPEN-

COST OF THE MOST

Source of Light.	1 Luminous intensities. C.P.	2 Measured for	3 Consumption per hour.	4 Total quantity of heat produced. (per hour) B.Th.U.	5 Heat developed per candle. (per hour) B.Th.U.
Gas (Flat flame)	16	Horizontal light intensity	5 cub. ft.	2660	166
Gas (Argand flame)	16	"	6·49 "	3450	216
Gas (Regenerative burner)	100	Mean hemispherical light intensity	14·1 "	7940	79·4
Gas (Incandescent)	50	Horizontal light intensity	3·85 "	2160	43·3
Spirit lamp (Incandescent)	30	"	·0164 gals.	1370	45·6
Petroleum	30	"	·0309 "	4140	138
Petroleum (Incandescent)	40	"	·0143 "	2370	59·1
Acetylene	60	"	1·38 cub. ft.	2305	38·5
Incandescent electric	16	Mean spherical light intensity	52 watts	179	11·2
Electric arc	450	Mean hemispherical light intensity	354 "	1205	2·68
Excello flame arc	2759	"	460 "	—	—

* After Prof. W.

NOTE.—Price of gas taken as 2*s.* 9*d.* per 1000 cub. ft.; petroleum

DIX II

USUAL SOURCES OF LIGHT *

6	7	8	9	10	11	12	13	14
Cost per 100 candle-hours.	Cost of burning per hour.	Mean hemispherical light intensity, cost of burning per 100 candle-hours, and quantity of heat developed per candle after burning 300 hours.						
		Without enclosure.			With enclosure.			
Pence.	Pence.	C.P.	Pence.	B.Th.U.	Enclosure.	C.P.	Pence.	B.Th.U.
1·03	0·165	10·6	1·55	250·5	—	—	—	--
1·34	0·181	10·4	2·06	332	Opal glass shade	14·4	1·49	240
0·465	0·465	100	0·465	79·4	„	100	0·465	79·4
0·248	0·124	29	0·428	74·7	„	40	0·31	54·1
0·383	0·1148	15	0·766	91·2	„	21	0·547	65·1
0·721	0·2163	20	1·08	207	„	28	0·773	148
0·25	0·1001	20	0·5	118	„	28	0·357	84·4
1·09	0·65	40	—	57·7	„	56	1·17	41·2
1·3	0·208	14	7·485	12·8	„	20	1·04	8·96
0·315	1·42	450	0·315	0·676	Alabaster globe	382	0·371	0·796
0·067	1·84	2750	0·067	—	„	2340	0·079	—

Wedding's table.

and spirit as 7*d.* per gallon; price of electricity as 4*d.* per B.T.U.

APPENDIX III

STANDARDIZATION RULES ON PHOTOMETRY AND LAMPS OF THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

341. **Candle-Power.**—The luminous intensity of sources of light is expressed in candle-power. The unit of candle-power should be derived from the standards maintained by the National Bureau of Standards at Washington, D. C., which standard unit of candle-power equals $\frac{100}{88}$ of the Hefner unit under Reichsanstalt standard conditions for the Hefner. In practical measurements seasoned and carefully standardized, incandescent lamps are more reliable and accurate than the primary standard.

342. **Candle-Lumen.**—The total flux of light from a source is equal to its mean spherical intensity multiplied by 4π. The unit of flux is called the candle-lumen. A candle-lumen is the $\frac{1}{4\pi}$th part of the total flux of light emitted by a source having a mean spherical intensity of one candle-power.

343. **Candle-Metre.**—The unit of illumination is the candle-metre. This is the normal illumination produced by one unit of candle-power at a distance of one metre.

344. (*a*) **Candle-Foot.**—Illumination is occasionally expressed in candle-feet. A candle-foot is the normal illumination produced by one unit of candle-power at a distance of one foot.

345. 1 candle-foot = 10·764 candle-metres. The use of the candle-metre unit is preferable and is recommended.

346. **The Efficiency of Electric Lamps** is properly stated in terms of mean spherical candle-power per watt at lamp terminals. This use of the term efficiency is to be considered as special, and not to be confused with the generally accepted definition of efficiency in Sec. 85.

347. (*a*) **Efficiency, Auxiliary Devices.**—In illuminants requiring auxiliary power-consuming devices outside of the luminous body, such as steadying resistances in constant potential arc lamps, a distinction should be made between the net efficiency of the luminous source and the gross efficiency of the lamp. This distinction should always be stated. The gross efficiency should include the power consumed in the auxiliary resistance, etc. The net efficiency should, however, include the power consumed in the controlling mechanism of the lamp itself. Comparison between such sources of light should be made on the basis of gross efficiency, since the power consumed in the auxiliary device is essential to the operation.

348. (*b*) **A Standard Circuit Voltage** of 110 volts, or a multiple thereof, may be assumed, except where expressly stated otherwise.

349. **Watts per Candle.**—The specific consumption of an electric lamp is its watt consumption per mean spherical candle-power. "Watts per candle" is the term used commercially in connection with incandescent lamps, and denotes watts per mean horizontal candle-power.

350. **Photometric Tests** in which the results are stated in candle-power should always be made at such a distance from the source of light that the latter may be regarded as practically a point. Where tests are made at shorter distances, as for example, in the measurement of lamps with reflectors, the results should always be given as "Apparent candle-power" at the distance employed, which distance should always be specifically stated.

351. **Basis for Comparison.**—Either the total flux of light in candle-lumens, or the mean spherical candle-power, should always be used as the basis for comparing various luminous sources with each other, unless there is a clear understanding or statement to the contrary.

356. "**Reading Distance.**" — Where standard photometric measurements are impracticable, approximate measurements of illuminants such as street lamps, may be made by comparing their "reading distances"; *i.e.* by determining alternately the distances at which an ordinary size of reading print can just be read, by the same person or persons, when all other light is

screened. The angle below the horizontal at which the measurement is made should be specified when it exceeds 15°.

357. **In Comparing Different** luminous sources not only should their candle-power be compared, but also their relative form, intrinsic brilliancy, distribution of illumination, and character of light.

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